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THE APPLICABILITY OF ADVANCED TECHNOLOGY IN SEWER SYSTEMS

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Alend W. ABDULRAZAQ

ABSTRACT

THE APPLICABILITY OF ADVANCED TECHNOLOGY IN SEWER SYSTEMS

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The need for using advanced technologies in existing and new constructed sewer system projects is essential to improve the system and minimize the probable malfunctions. For several reasons, the frequency and severity of malfunctions in sewer systems are observed to be much more in developing countries than in the developed ones. The implementation of advanced technologies in sewer systems has clear advantages, but in some circumstances, accompanied with some difficulties that limits its use. In this research, the feasibility of several types of advanced technologies relevant to sewer systems was investigated. Among those technologies, the hydraulic efficiency of the implementation of non-circular pipes in sewer systems or through lining existing systems was investigated. Also, computer program packages that are used for the design of gravity flow sewer systems have been investigated in order to evaluate their applicability. Different other advanced technologies were also presented and investigated. The availability and applicability of those advanced technologies in developing countries were investigated.

Key words: Sewer system; Non-circular pipes; Egg-shaped pipes.

ÖZET

KANALİZASYON SİSTEMİ TEKNOLOJİLERİNİN UYGULANABİLİRLİĞİ

ABDULRAZAQ, Alend
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Mevcut ve yeni inşa edilen kanalizasyon sistemi projelerindeki arızaları en aza indirgemek ve sistemi iyileştirmek amacıyla, gelişmiş teknoloji kullanmak temel bir ihtiyaçtır. Birçok nedenden dolayı, kanalizasyon sistemlerinin arıza sıklığı ve şiddeti, gelişmiş olan ülkelerden daha çok gelişmekte olan ülkelerde olduğu gözlenmektedir. Kanalizasyon sistemlerinde gelişmiş teknolojilerin uygulanmasının belli avantajları vardır, ancak bazı durumlarda, eşlik eden bazı zorluklar bu teknolojilerin kullanımını sınırlamaktadır. Bu çalışmada, kanalizasyon sistemi ile ilgili çeşitli gelişmiş teknolojilerin fizibilitesi araştırılmıştır. Bu teknolojiler arasında, dairesel olmayan boruların uygulamaları kanalizasyon sistemlerinde veya mevcut sistemlerin astar yoluyla, hidrolik verimliliği araştırılmıştır. Ayrıca, yer çekimi ile akan kanalizasyon sistemlerinin tasarımında kullanılan bilgisayar programlarının uygulanabilirliğini değerlendirmek amacıyla incelenmiştir. Değişik gelişmiş teknolojiler sunulmuştur ve araştırılmıştır. Bu teknolojilerin gelişmekte olan ülkelerdeki mevcudiyeti ve uygulanabilirliliği araştırılmıştır.

Anahtar kelimeler: kanalizasyon sistemi; Dairesel olmayan borular; Yumurta şeklinde borular.

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CHAPTER 1

INTRODUCTION

Designing and constructing sewer systems in urban regions require high accuracy and perfection. If the selection of the pipe is wrong due to the wrong estimation of the amount of sewage, and/or if the hydraulic limitations of sewer pipe such as pipe slope, size, and cross section are wrongly determined, then, an overflow is likely to occur. Consequently, this may cause health and other hazards due to polluting the surrounding area. In other words, one of the common problems in sewer systems is the flow velocity being below the allowable minimum limit. Usually, this leads to the settlement of sediment in sewage water, which leads to the sewer blockage. For several reasons, the frequency and severity of such malfunctions are observed to be much more in developing countries rather than in the developed ones.

The difference between developed and developing countries can be observed regarding several aspects of life, and not only in the difference of technical and financial levels. Obviously, this makes the application of some useful new scientific achievements/ methods relatively more difficult in developing countries. Frequently, such difficulties are not related merely to the lack of funding, it may be related to the lack good administration, or, the lack of data, or, the lack of good coordination among the different government sectors, or, a combination of all.

Specifying the problem and obstacles should ease the way towards the solution, and could be described as the first step towards the targeted satisfactory solution. In developing countries, the performance of sewer system nets is frequently observed to be less than satisfactory, and sometimes, could create serious problems. This observation increases the need to improve the system by means of using advanced technology.

This research is intended to investigate the different aspects of advanced technology that could be applied to sewer system. Also, to investigate the problems encountered regarding its applicability in developing countries, especially when the main obstacle does not appear to be the financial limitations. Among those aspects that could be the focus of investigation of the different models of sewer collector (egg-shaped), the applicability of flow measurements in sewer system, the new methods used for releasing the flow in case of blockage, the availability of ready programs for sewer system design flowing by gravity, and also, communicating with as many municipalities as possible in order to specify the difficulties encountered against any of the new techniques in sewer systems. Also, in case any of the advanced technology systems appear to be already applied in the local systems, then, the degree of success and the different types of problems encountered would be investigated

Several aspects for probable improvement of sewer system performance were investigated from the hydraulic aspect, such as non-circular cross sections in order to numerically clarify the expected improvement when replaces circular pipes. On the other hand, more than one package computer program, used for gravity flow sewer systems, have been investigated in order to evaluate their applicability in developing countries. Different advanced technologies were presented. Also the availability and applicability of those advanced technologies in developing countries were investigated through communications with some municipalities.

The aim of this study is likely to improve both the economy and public health in by means of improving the efficiency of the existing sewer system. This could be achieved by means of decreasing the frequency and severity of malfunctions in sewer system, and also, reduce the cost of maintenance, which should lead to more satisfactory results regarding such facility that is essential to the health and convenience of urban regions.

1.1 Sewer System

Sewer is an artificial conduit or system of conduits used to remove sewage and to provide drainage. Domestic sewers are usually pipelines that begin with connecting pipes from buildings to one or more levels of larger underground horizontal mains, which terminate at sewage treatment facilities. Vertical pipes, called manhole, connect the mains to the surface. Sewers are generally gravity powered, though pump may be used if necessary [1]. In general, there are two types of sewer systems in a city. Combined and separate sewer systems. The selection of the suitable type depends mainly on the availability of the financial sources and data to perform whatever necessary.

1.1.1 Separate Sewer System

A separate sewer system is a type of sewer system which one pipe system carries waste water and separate pipe system carries storm water.

1.1.1.1 Storm Sewer System

Storm sewer is designed to drain excess rainfall and groundwater from paved streets, parking lots, sidewalks, and roofs. It varies in design from small residential dry wells to large municipal systems. Storm sewer are present on most motorways, freeways and other busy roads, as well as towns in areas which experience heavy rainfall, flooding and coastal towns which experience regular storms [1].

1.1.1.2 Sanitary Sewer System

Sanitary sewer is a type of underground carriage system for transporting sewage from houses or industry to treatment or disposal. Sanitary lines generally consist of laterals, mains, and manholes (or other various forms of traps) [1].

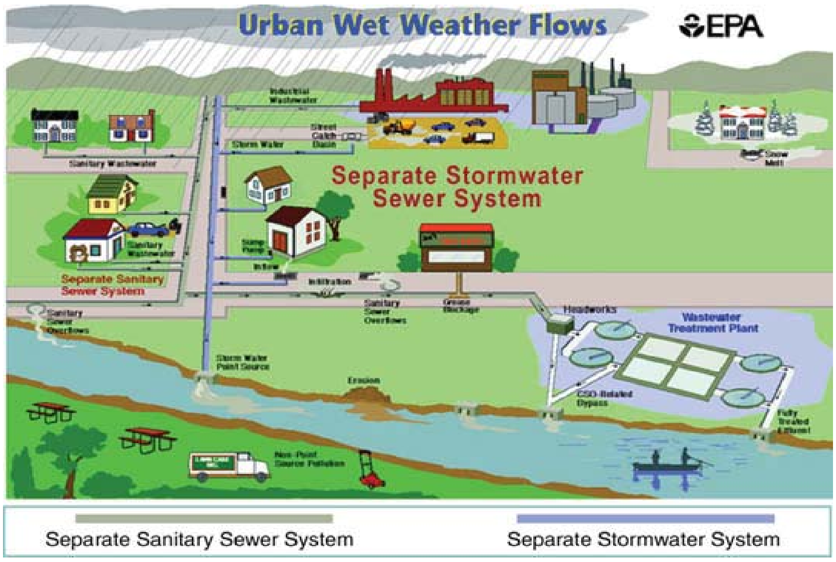


Figure 1.1 A typical separate sewer system [1].

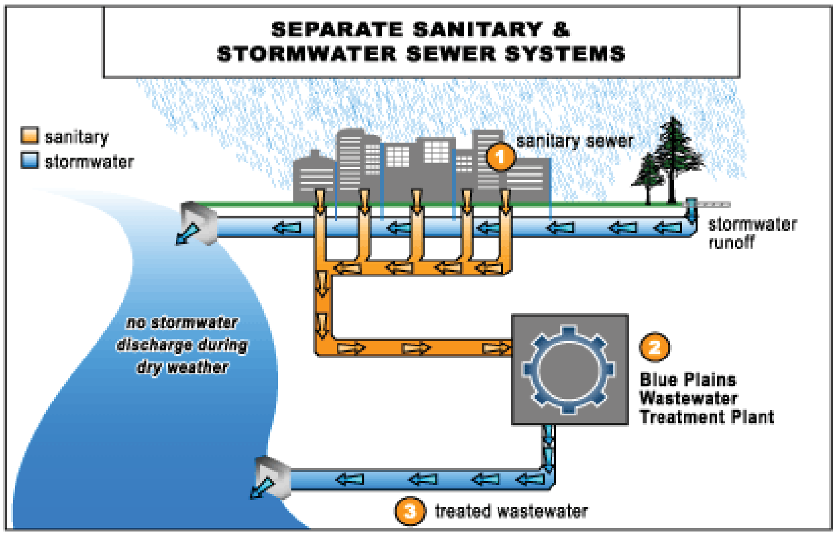


Figure 1.2 Separate sanitary and stormwater sewer system [2].

A. Advantages of Separate Sewer System

The following are the advantages of the separate system:

I- Since the sewage flows in separate sewer, the quantity to be treated is small which results in economical design of treatment works.

II- Separate system is cheaper than combined system, because only sanitary sewage flows in closed sewer and storm water which is not foul in nature can be taken through open channel or drains, whereas both types of sewage is to be carried in closed sewer in combined system.

III- During disposal if the sewage is to be pumped, the separate system is cheaper.

IV- During significant rainfall, there is no fear of stream pollution [3].

B. Disadvantages of Separate Sewer System

The following are the disadvantages of the separate system

I- Flushing is required at various points because self-cleaning velocity is not available due to less quantity of sewage.

II- There is always risk that the storm water may enter the sanitary sewage sewer and cause over-flowing of sewer and heavy load in the treatment plant.

III- Maintenance cost is more because of two sewers.

IV- In busy lanes laying of two sewers is difficult which also causes great inconvenience to the traffic during repairs [3].

1.1.2 Combined Sewer System

A combined sewer is a type of sewer system which provides partially separated channels for sanitary sewage and storm water runoff. This allows the sanitary sewer system to provide backup capacity for the runoff sewer when runoff volumes are unusually high, but it is an antiquated system that is vulnerable to sanitary sewer overflow during peak rainfall events [1].

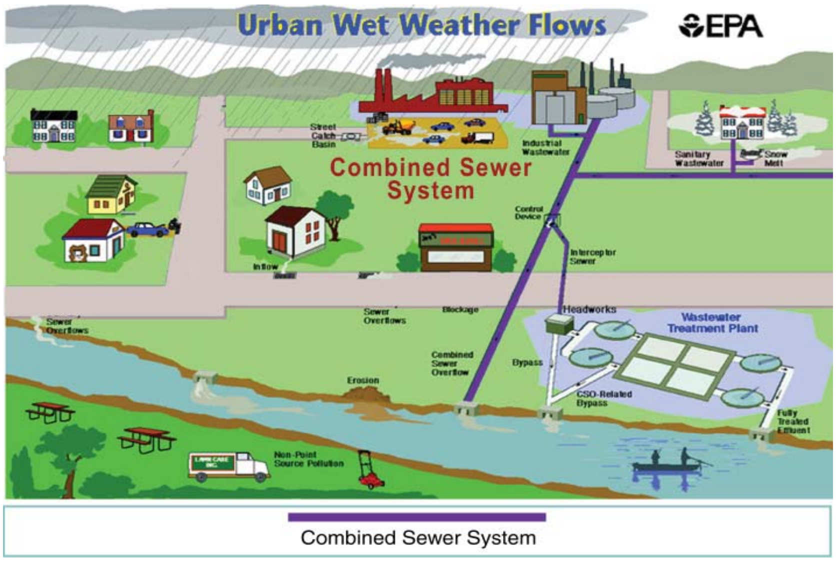


Figure 1.3 A typical combined sewer system [1].

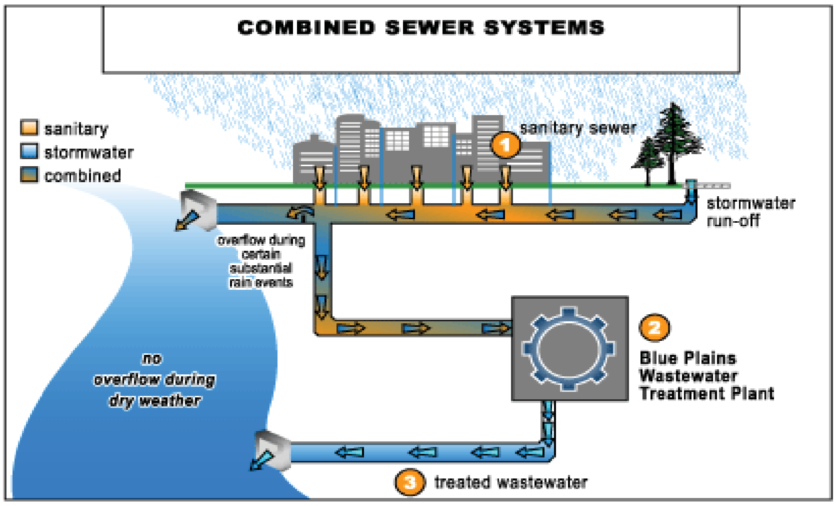


Figure 1.4 Combined sewer system [2].

A. Advantages

The following are the advantages of combined system:

I- There is no need of flushing because self-cleaning velocity is available at every place due to more quantity of sewage.

II- The sewage can be treated easily and economically because rainwater dilutes the sewage [3].

B. Disadvantages

The following are the disadvantages of combined system:

I- The initial cost is high as compared to separate system.

II- It is not suitable for areas having rainfall for smaller period of year because resulting in the silting up of the sewers due to self velocity is not available.

III- During heavy rainfall, the overflowing of sewers will endanger the public health.

IV- If whole sewage is to be disposed of by pumping, it is uneconomical [3].

CHAPTER 2

AN ASSESSMENT OF COMMON SEWER SYSTEM PROBLEMS

Minimizing the need for sewer systems repair and renewal can be achieved only through careful planning, design, and operation. However, this objective is rarely achieved [4]. The responsibility of the quality of sewer systems can be related to three main parties: the government; the sectors responsible for the design; operation and maintenance of the project; and the citizens. The government, in its wide definition, is certainly considered to be the main coordinator, and it takes most of the responsibility of the success or failure of the project. This is due to having the power to control all the performance of the relevant sectors involved in the project, and also, due to having the power to educate citizens about the proper use of sewer systems and punish the ones who might cause any damage [5].

2.1 Sewer Overflow and Blockage

2.1.1 Sewer Overflow

A. Wet Weather Overflow

During heavy rains, when storm water gets into the system/especially combined sewer system, the pipe can become full (under pressure) and spill over. These spills, called sewer over flows, as usually occur at a manhole and overflow in to street or yard, they are considered “wet weather overflows” [6].

B. Dry Weather Overflow

In combined sewer system and sanitary sewer system, also overflow can occur when a pipe gets clogged with debris, grease or roots, these sewer over flow are considered "dry weather overflow", as opposed to the "wet weather overflows" [6].

Figure 2.1 Water escapes through a manhole during an overflow event [6].

2.1.2 Sewer Blockage

Some of the most common causes of sewer blockage are:

1- Build-up of grease, debris or foreign objects in the sewer lateral or district sewer main.
2- Partial or complete blockage caused by tree root intrusion into sewer pipes.
3- Sewer line collapse caused by old and deteriorated sewer pipes.
4- Debris entering the sewer system from illegal pipe connections [7].

A. Roots

Roots grow toward breaks and cracks in the pipes in search of a source. If roots get inside the pipe, they form root balls that clog the line [7].

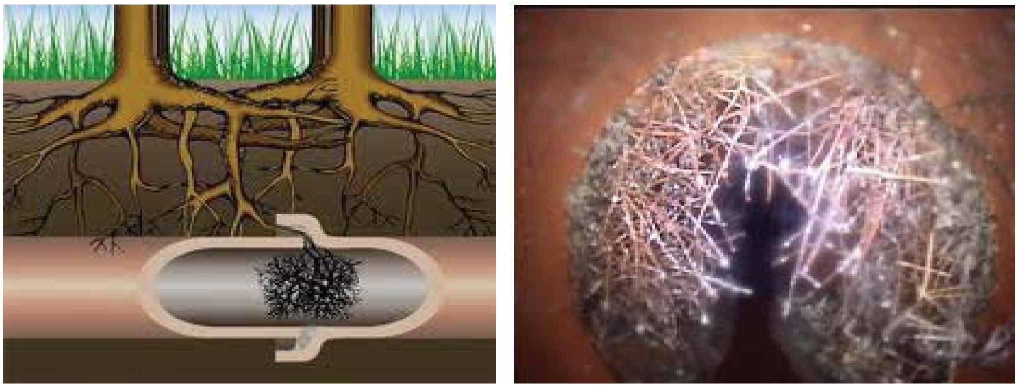


Figure 2.2 Root intrusions in sewer pipe [7, 8].

B. Grease

Grease collects and hardens inside the pipes and forms a plug.

Figure 2.3 Grease buildups in sewer pipe [7].

2.2 Reasons for Overflow and Blockage Events in Sewer System

Factors affecting overflow and blockage of the sewer system are:

2.2.1 Common Errors in Planning, Design and Construction

The errors usually made during the planning, designing and construction stages may be defined as follows:

A. Designing a Sewer Net as a Combined System Instead of a Separate One

This error causes exponential increase on the error made in estimating the combined design discharge [9, 10]. It is obvious that in spite of having a relatively higher initial cost, a separate system would serve better and live much longer than a combined one. However, the decision in designing the project as a combined system is frequently imposed by the higher authorities due to economic limitations and/or political reasons [5].

B. Poor Alignment of Pipes in Sewer Lines

If the pipes of a sewer line are not installed in a straight alignment, the occurrence of unaccounted- for head loss, blockage, and leakage events from pipe joints are inevitable. One of the possible reasons for such error is careless execution, such as poor pipe bedding, or, neglecting the bedding all together. Another reason could be the occurrence of differential settlement or swell, in the soil surrounding the pipes, due to changes in moisture content [11]. Also, this could result from traffic load when exceeding the recommended limits. Such zigzag-like alignment is observed to occur in three dimensions. The horizontal deformation in alignment is usually the result of careless execution, while the vertical one could be the result of careless execution and/or of soil settlement or swell. For the same angle between two successive pipes, the pipes with relatively smaller diameter are more exposed to suffer blockage and pressurized flow problems than the pipes with larger diameter. This is due to the relatively little tolerance in free space between water surface within the pipe and the crown.

On the other hand, for the same angle between two successive pipes, the exposed gap at the joint increases linearly with the increase of the diameter. This gap enables sewage water to seep out of the pipes, and groundwater to infiltrate in. Also, this would enable the surrounding soil to infiltrate into the pipes and cause blockage and overflow [5].

C. Poor Joints between Pipes

Generally, this is the result of low-quality execution and not necessarily relevant to the alignment between two successive pipes as explained in the previous paragraph. Successive pipes may be aligned properly but with poor joints. In fact, the use of bonding material at the joint section is commonly poor and unsatisfactory. Observations indicate that, in some cases, pipes are just laid in series without applying any bonding materials whatsoever at the joint sections. This error results in exchanged infiltration from and into pipes, [12] as explained in the previous paragraph. The exchanged infiltration may be due to change in the moisture content of the surrounding soil with consequential swell or settlement. The resultant change in the volume of soil is likely to enlarge the existing gaps at the pipe joints, and this would enable for more exchanged infiltration, and so on (a case of positive feedback). Moreover, the infiltration from sanitary sewer pipes to the surrounding soil may cause health hazard to the nearby regions, and also, may decrease the discharge and velocity of flow to a limit that would cause sediment settlement in the pipe net. Unfortunately, it is commonly observed that when sewage water infiltrates through the gaps between sewer pipes, a section of that water is likely to reach the nearby fresh water supply pipes and infiltrate into that net through any existing fractures during low-pressure periods. The latter case is encountered during the frequently experienced periods of domestic water shortages, when the pressure within that net is close to atmospheric. This event is observed to occur frequently with certain spread of epidemic diseases that may be fatal to children and old citizens [5].

D. Unapproved On-Site Alterations Made by the Executive Sector without Informing the Central Design Office

Such events are observed to frequently take place during the finding of an unreported existing infrastructure. After such finding, due to the expected and unpaid delay in making the necessary alterations by the design office, the executing sector would try its best, with all the good intentions, to solve the problem locally as quickly and quietly as possible. Unfortunately, such solution is unlikely to be correct, or at least, is unlikely to increase the formally predicted total head loss within the system. The latter case would result in inevitable overflows within the system. In such case, it is unfair to put all the blame on the executive sector [5].

E. Wrong Prediction in the Population Increase and/or of the Relevant Daily Water Consumption

This error may occur due to the lack of reliable statistics and/or using simplified prediction methods that do not fit the social, economic, and climatic factors within the region in concern [5].

F. The Random Expansion of a City

Usually, the quick increase in population of a city is accompanied by a quick unplanned expansion in its zones, also, by the random appearance of squatter areas. The random expansions made on the existing sewer system causing inevitable disruption to the predicted flows within the net with variable degrees of consequential damages and overflows [5].

G. Low-Quality Materials Selected for the Construction of the Project

This includes all what may be required for the construction and maintenance works such as pipes, cement, aggregates, joints, manholes, manhole caps, etc. Here, the section responsible for the approval of the quality of the used materials is the guilty one. The reason behind such approval is either the lack of experience, or accepting bribes from the suppliers.

However, one more reason could be that the required materials for construction are made by governmental sectors of poor quality with no alternative choice [5].

H. Neglecting the 3 cm Drop in Pipe Elevation at the Manholes with a Change In Alignment without a Change in Pipe Diameter

Obviously, this drop is meant to compensate for the energy loss caused by the change in direction [13, 14]. When such drop is neglected in the design and/or execution, an accumulation of sewage water is expected to take place in pipes with various damaging consequences such as pressurized flow, settlement of sediment, and overflow.

I. Soil Entering Sewer Pipes through Open Manholes and/or Open Excavations During the Period of Construction and Repair

In this case, the active forces in the process are rainfall splash and overland flow [15, 16]. The damaging consequences of such event are usually severe and difficult to repair. This is because when soil is washed down to a sewer system, it spreads over long distances throughout the pipe net. The damage caused to the system becomes more severe when the sand used for construction purposes is piled up close to a manhole, or close to an excavation site, without protective boundaries. Consequently, a large portion of the sand would be washed down by rain into the sewer system. Unfortunately, it is observed that the required simple precautions to minimize the occurrence of this problem are frequently neglected [5].

J. Wrong Estimation of Pipe Fullness Ratio

When safety factor is taken to be relatively little, a relatively large fullness ratio in pipes is usually selected.

In this case, the negative influence of one error or more in the design, execution, or operation is unlikely to be tolerated. On the other hand, when safety factor is taken to be relatively large, a relatively low fullness ratio in pipes is usually selected. The latter case is likely to result in the flow velocity being below the lower limits during low-flows, and consequently, causing sediment deposition in pipes. In fact, the selection of fullness ratio in sewer pipes is an extremely sensitive matter and should be determined depending on the local conditions of the relevant region regarding the reliability of the data, design, execution, and operation of the project. Unfortunately, the common application during the design is to take the recommended pipe fullness ratio from tables that relate this ratio only to the selected pipe diameters without considering any other factors [5].

K. Long Distance between two Successive Manholes

This would cause difficulties in clearing any blockage and/or finding the location of the blocked section within the relevant alignment. In developing countries, the distance between manholes is supposed to be treated as variable, which depends on local conditions, rather than just being a strict value taken from design tables. In other words, the maximum distance between every two successive manholes in a sewer system should decrease with the decrease of the expected quality of the project. Of course, the main problem here is to admit formally and in advance that the quality of the project will be less than the required standard. Admitting such thing indirectly means approving it [5].

L. Exceeding the Permitted Limit of Traffic Load

Invisible damages may be caused to sewer systems if the traffic load is not controlled properly and/or if the depth cover is designed to be less than safe for the expected traffic loads. The latter case is observed particularly in small cities that grow larger with an unexpected rate, in villages, and in housing cooperatives. The matter starts with the idea of minimizing the initial cost of the project through selecting a depth cover of around 1 m. However, by the time a heavy lorry or a fire brigade vehicle is in action, it would be too late to do much about preventing the damage [5].

M. The Discharge of Sewage into Rivers at the Wrong Elevation

Although the direct discharge of untreated sewage water into rivers is internationally prohibited, due to several reasons, many cities in developing countries overlook the environmental damages caused by this application. In such case, an error is frequently made in selecting the proper elevation of discharge points at the riverbank. Such error leads to frequent backflows in the sewer net during the periods of high flows in the river. In such case, frequently maintained non-return valves may be a partial solution to the problem [17].

N. Improper Elevation of the Link between Pipe Lines at Manholes

This implies neglecting the rules of sewer design in two cases. The first case is in linking two or more pipes to a manhole, where pipe crown elevations are supposed to be the same even with an increasing pipe diameter. The second case is in linking a branch pipe with the main one. In the latter case, the crowns are supposed to be of the same elevation unless the branch pipe would enable for a drop of 60 cm or more in case left to be parallel to the street [14]. In fact, the observed applications in sewer system construction are far from applying such delicate rules. In particular; the link between the main and branch pipes is frequently made wrongly in such a way that the branch is linked directly to the middle of the main pipe without a manhole at the joint section. In such case, backflow and leakage events are inevitable. In manholes, a depression of at least 5 cm is useful to trap the sediment and trash that may infiltrate into the system. In general, this depression is frequently neglected, and consequently, blockage events are frequently encountered at the lower section of pipe joints with poor alignment (as explained previously), and also, at the manholes with a change in alignment [5].

O. The Flow Exceeding the Allowable Velocity Limits

This would cause damage to the sewer system in the case of high velocities, and also, the settlement of sediment load in the case of low velocities [18].

P. Inaccurate Execution of the Elevations, in General

This includes all elevations relevant to pipes manholes. The error made in making manhole surface elevations (caps) higher or lower than street elevation is frequently encountered. The severity of the error involving manhole cap elevation is frequently made worse by the overlapping layers of asphalt used for the renewal of road pavement without scraping the old ones. This incompatible elevation of manhole caps is extremely dangerous to traffic due to the drivers attempt to avoid the manhole caps by a swift that is usually unexpected by the driver behind. Drivers usually try their best to avoid manholes not only because of their elevation is wrong, but also due to the probability of some manholes being left without caps at all and without warning signs. Obviously, with the normal speed of the traffic, it is practically impossible to see from a distance whether the manhole has a cap or not. Therefore, for most drivers, the risk made in a quick swift to avoid passing over a manhole is relatively less than behaving otherwise [5].

Q. The Approval of Poor-Quality Construction Works

This is frequently encountered when the government control engineer is inexperienced, or has some weaknesses that can be manipulated by contractors. Interestingly, poor-quality execution is beneficial to the contractors in two ways. Firstly, the cost of poor-quality construction works is relatively less, and secondly, poor quality works are not durable, which means that the calls for renewal works are frequent and would keep contractors in action. This explanation does not exclude the existence of three other cases, that is when the contractor is decent but inexperienced, or, is decent and experienced but negligible, or, is decent and experienced and completes the required works properly. Unfortunately, the indecent methods used by some contractors make the pressure on the decent ones unfairly high in many ways [5].

2.2.2 Common Errors in Operation, Maintenance and Repairs

The main errors usually made during the operation and maintenance phases of sewer systems may be summarized as follows:

A. Leaving Manholes Uncapped or Improperly Capped

This error is usually made after a routine maintenance process. In this case, the active forces in the process are rainfall splash and overland flow [15, 16]. The damaging consequences of such event are usually severe and difficult to repair. This is because when soil is washed down to a sewer system, it spreads over long distances throughout the pipe net. The damage caused to the system becomes more severe when the sand used for construction purposes is piled up close to a manhole, or close to an excavation site, without protective boundaries. Consequently, a large portion of the sand would be washed down by rain into the sewer system.

Unfortunately, it is observed that the required simple precautions to minimize the occurrence of this problem are frequently neglected [5].

B. The Disposal of Industrial Sewage and Wastes into Sewer Systems without Filtration or Treatment

This error is frequently observed with the obvious risks of pollution and of the accumulation of solid wastes in sewer pipes. Although considered extremely unhealthy practice, it is known that untreated sewage water is frequently used for irrigation purposes in developed countries. In this case, the presence of industrial pollutants in sewage water is likely to decrease the quality of crops irrigated by such water, and also, may cause health hazard to the consumers of such crops [19].

C. The Incompatibility of Treatment Plants with the Characteristics of Sewage

In developing countries, it is common that treatment plants be designed and constructed by companies from developed countries. Naturally, the design would be based on a specified range of a group of relevant variables, such as the discharge, type and degree of pollution, content of solid materials, etc [20].

D. Neglecting the Required Periodic Maintenance of the System

If the required periodic maintenance in checking manholes and pipes is neglected, then, the accumulation of sediment and solid materials is likely to be consolidated by the time, and eventually, cause blockage and overflow within the system [21, 22, 23].

2.2.3 Misuse and Abuse by Citizens

The errors made by some citizens may be explained as follows:

1- The caps of manholes are frequently stolen, melted, and sold as scrap metal. This matter is difficult to detect and control. The consequences are extremely damaging to the system, and also hazardous to the public. Open manholes enable the entry of large solid materials, which is likely to cause blockage in the system. This is besides being extremely dangerous to pedestrians and traffic as explained previously. Naturally, manholes with stolen caps would be without warning signs, and moreover, they are likely to continue being without signs even after being reported to the formal authorities. The official authorities need time and allocated money to take action against such endless problem. Usually, time is available while the case is different for money. As a rough and practical solution to this common problem, manhole cap are frequently switched from the font type into the concrete one.

2- Farmers breaking the main collector pipe in order to divert water for their irrigation needs. This is a strange practice used occasionally by some local farmers. This behavior indicates severe irresponsibility and lack of education. Usually, local farmers break the main collector and install a semi-perpendicular barrier in order to divert a section of the flow towards the nearby lands to be used for irrigation purposes. This diversion causes increase in the resistance against the flow. In other words, this would cause serious overflow problems within the upstream side of the sewer system; after the municipality finds out about the matter; a classic investigation would be started. However, it is always difficult to specify the personals responsible for such damage. This is simply because such diverted water would serve the need of several farmers and not a single one.

3- The lack of education regarding the proper use of sewer system, poorly educated citizens think that whatever enters the sewer system would certainly find its way somehow without any problem. This thinking encourages the act of throwing solid materials and large objects into the system without hesitation. Among those objects found, plastic containers, bottles, rags, plastic bags, organs of slaughtered animals, etc. Some officials reported finding even dead animals of small and medium sizes (cats, dogs, and sheep) in sewer systems [5].

2.3 Internal Erosion of Pipes

Erosion is the wearing away of material by physical and chemical force. Sewer system mainly eroded due to sulfuric Acid or Acid. This causes serious threat to the structural integrity of the system as well as large amount of maintenance and repair costs in the environmental conditions [24].

Figure 2.4 Eroded concrete in sewer pipe [25].

2.4 Earthquake Effects on Sewer Pipe Line

During Earthquake, the infrastructure such as; deep tunnels and sewer system pipes may exposed to serious damages, especially when duration of tremor takes long time, then, the pipe line starts to shake, and consequently, the liquid velocity will increase leading to water hammer, then to pipe line destruction. According to Hamilton principle, it could be concluded that under the earthquake excitation, pipe with low intensity and soft foundation can be more easily destroyed than that with high intensity and hard foundation. So, the characteristic of foundation have a great influence on pipe destruction [26].

2.5 External Corrosion of Sewer Pipes

Corrosion is a natural chemical and electrical process that is, by definition, accompanied by the flow of electrical current. Humidity, high temperature, high chloride sulfate, etc provide the most hostile environment to the pipes, either buried or above ground, leading to failure. Corrosion occurs in the anodic areas of the pipe line and is associated with the flow of current from the pipe to the soil. A schematic view of the corrosion of buried pipe is shown in Figure 2.5 [27].

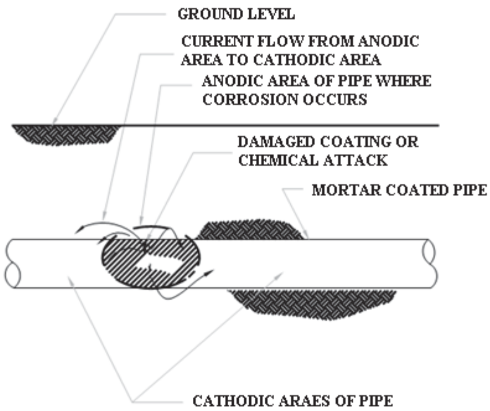


Figure 2.5 A schematic view of the corrosion of buried pipe [27].

Figure 2.6 Indicates corrosion of a concrete pipe [28].

2.6 Soil Swelling Effects on Sewer Pipe

Swelling soil contain clay minerals that attract and absorb water. As a result, these soils expand when they get wet and shrink when they dry. When swelling soils become wet and expand, the resulting swelling pressure can cause uplift against concrete foundation footings, causing a wide variety of damages such as; broken pipe and water lines, and cracking and heaving of concrete foundations [29].

2.7 Sectors that Deals with the Problem (Sewer System Overflow and Blockage)

Usually, both government and private sectors are responsible, with variable degrees, for the planning, execution, operation and maintenance of sewer system projects. The sectors commonly responsible for the different steps taken for the completion of a typical sewer project may be explained as follows:

2.7.1 Data Supplying Sectors

A- Population density obtained from the government statistical department, which includes:

i- Knowledge of the city and its environs,
ii- Its trade territory,
iii- Whether or not its industries are expanding,
iv- The water shipment of raw materials and manufactured goods will all enter into the estimation of future population,
v- Of course, extraordinary events, such as discovery of a nearby oil field or sudden development of a new industry [30].

B- Social standards, habits, and the size and type of industrial activities along with their water relevant parameters. The latter includes the discharge of disposed water per day as well as the type and magnitude of pollutants. These data should be available from the government statistical department and from the local municipality [5].

C- Geological maps of the location of the proposed sewer project this should include the characteristics of soil, groundwater variations, and earthquake history of the region in concern [5].

D- Topographic maps of the region in concern, usually, obtained from the regional municipality.

E- Meteorological statistics, Meteorologists analyze and forecast weather, provide consultation on atmospheric phenomena and conduct research into the processes and phenomena of weather, climate and atmosphere. They are employed by private consulting companies, resource and utility companies and by provincial governments or they may be self-employed [31].

F- Data relevant to the quality, cost, skills, and materials for construction. The latter includes the available pipe diameters, types of manholes, and also all the required peripherals. These kinds of data are obtained from the government and/or private sectors.

These data, if available, are usually obtained from the regional municipality, so the sectors which are responsible for the feasibility studies and final designs will entirely depend on such data's [5].

2.7.2 Sectors that Supplies the Necessary Material of Construction

This includes all what may be required for the construction and maintenance works such as pipes, cement, aggregates, joints, manholes, manhole caps, etc. Here, the section responsible for the approval of the quality of the used materials is the guilty one. The reason behind such approval is either the lack of experience, or accepting bribes from the suppliers. However, one more reason could be that the required materials for construction are made by governmental sectors of poor quality with no alternative choice [5].

2.7.3 Sectors Responsible for the Execution of the Project

This is frequently encountered when the government control engineer is inexperienced, or has some weaknesses that can be manipulated by contractors.

2.7.4 Sectors Responsible for the Approval of the Completed Works

The approval is usually given in accordance with the time schedule and the quality specified in the signed contract. Usually, this sector is governmental.

2.7.5. Sectors Responsible for the Operation and Maintenance

This situation is commonly observed in both government and private sectors.

2.8 Proposed Solutions for Sewer System Problems

2.8.1 Solution for Feasibility Study

In Figure 2.7, the combined sewer line is equipped with a control device, before it reaches the stream. The device diverts the flow into the interceptor sewer, which takes it to a sewage treatment plant. In dry weather, all of the flow is sanitary sewage, and the interceptor line can handle it. In wet weather, storm water mixes with the sanitary sewage, increasing the flow. If the flow is large enough, part of the water may flow over the weir and through the combined sewer overflow (CSO) into the stream.

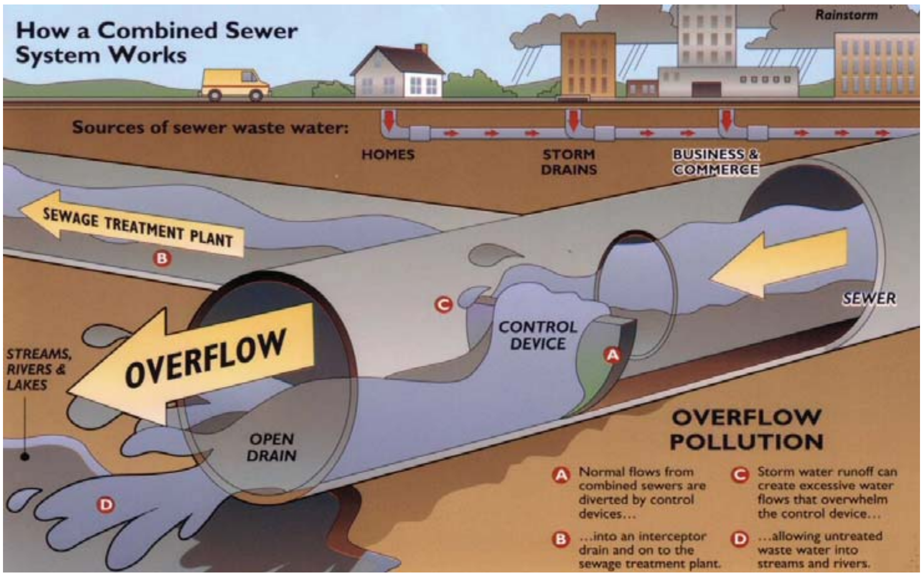


Figure 2.7 Combined sewer system overflow during dry and wet weather [32].

The equipped device allows overflow water to enter the stream, but prevent stream water from entering the sewers [33].

2.8.1.1 Sewer Separation Basics

In areas where the existing combined sewer system provides adequate drainage, construction of new sanitary sewers may be recommended. Although construction of new sanitary sewers can be a more costly sewer separation approach, it offers valuable benefits. New sanitary sewer materials and construction methods result in a water-tight system that minimizes infiltration/exfiltration, maximizes reliability and provides a new useful life. If the new sewers are sized properly for post-separation flow rates, basement flooding can be eliminated. If the existing system is significantly undersized for peak stormwater runoff, it may be desirable to use existing sewers for the new sanitary sewer system and construct new storm sewers [33].

2.8.1.2 Green Separation

An emerging combined sewer overflow control alternative using a combination of sewer separation and green infrastructure is worth considering. Environmental Protection Agency defines green infrastructure as systems and practices that use natural processes to infiltrate, evapotranspirate (the return of water to the atmosphere either through evaporation or by plants), or reuse stormwater or runoff on the site where it is generated.

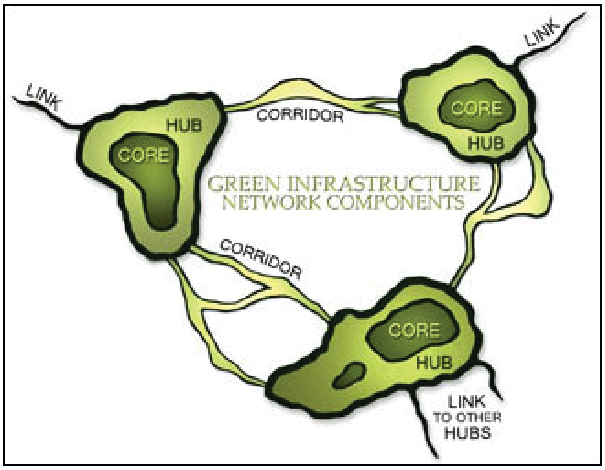


Figure 2.8 Green infrastructure definitions [34].

The term green infrastructure gained currency in the late 1990s as concerns about climate change and scarce resources heightened interest in sustainable urban development [35]. Green Separation uses sewer separation and green infrastructure to eliminate CSOs, reduce stormwater runoff, and improve stormwater quality [33].

Figure 2.9 NE Siski green street projects, Portland, Oregon [33].

2.8.1.3 Shallow Separation

In some communities, it is feasible to discontinue gravity sanitary sewer service to basement-level fixtures. In this approach, a new gravity or vacuum sanitary sewer system would be installed only as deep as required to serve fixtures at ground level or above. Shallow, watertight sanitary service leads would be constructed for existing properties with existing basement service and deep service leads. Existing basement-level fixtures would either be abandoned, or the flow pumped to the new service lead. For example, most washing machines have pumps capable of pumping to the new service lead elevation [33].

2.8.2 Solution for Sectors that Supplies the Necessary Material of Construction

It is essential to improve laboratories that used for construction materials; this would be performed by providing new equipments/devices that have high accuracy for testing materials, and also, sending out skillful engineers for scientific courses to get sufficient practice on such devices. On the other hand, making a high quality control center for imported materials and local production materials is essential matter to verify the quality of materials. This pursuance must be in a fair manner.

2.8.3 Solution for Sectors Responsible for the Execution of the Project

This would be solved and controlled during daily execution steps and taking essential notes regarding faults and malfunctions. In fact, this could be achieved by providing experience engineers to visit the site and controlling whatever necessary.

2.8.4 Solution for Sectors Responsible for the Approval of the Completed Works

Usually, this sector is governmental, so it is necessary to approve all the works properly to avoid the main problems that explained previously, also the site engineer has to visit the project permanently in order to be able to control any malfunctions or problems during execution, then, warn or guide them to complete the imperfections. Obviously, executing any engineering projects according to design standards and engineering specifications will decrease faults, and consequently, increased the quality of the project.

2.8.5 The Sector Responsible for the Operation and Maintenance

In order to solve this situation, it is necessary to provide detailed city maps which show the location of manhole and pipe alignments. Periodic records should be kept in order to monitor the situation of pipes and detect the excessive sediment and blockage along the sewer line. Sewer pipes should be cleansed periodically. On the other hand, the location of manhole should not be exceeded a certain limit regarding the distance between two successive manholes which is usually constrained by the municipality. The latest is that after each operation the cap of the manholes that removed for maintenance has to be recovered, this is why many problems happened to the pedestrian in falling in to the manhole and other accidents like falling car tire, pets, and the like.

2.9 Comments

The need for maintaining the existing sewer systems and for the construction of new ones must continue with the continuation of life itself. Consequently, this leaves no chance to think of a temporary halt of any kind of sewer relevant activities until the current problems are solved, especially when the required period for solving these problems cannot be defined. Alternatively, the efforts to solve the common problems of sewer systems and improve their standard must be made simultaneously while all activities continue as usual. This investigation reveals that with the same cost of the project, paying attention to some simple details during the different stages of sewer system projects is likely to improve the quality significantly.

With the exception of the common financial limitations in developing countries, it can be concluded that most of the different type's sewer problem causatives are originally related to the lack of education. This indicates clearly that education is certainly the long-term solution, while preventing the causatives of the current sewer problems is the short- term solution for the time being. In order to achieve a satisfactory and permanent solution to these problems, the efforts must be equally divided in both directions [5].

CHAPTER 3

ADVANCED CONSTRUCTION TECHNOLOGIES IN SEWER SYSTEMS

3.1 Advanced Technologies for New Sewer System Projects

3.1.1 Trenchless Technology for New Construction

Trenchless technology, often referred to as "no dig", is a rapidly growing engineering industry that eliminates the need for surface excavation. Trenchless technology is also used to minimize environmental damage and to reduce the costs associated with underground work [36].

3.1.2 Trenchless Methods for New Construction

The trenchless construction methods available for new facilities are divided into two main classes: Horizontal Earth Boring, which is performed without workers being inside the borehole, and Pipe Jacking / Utility Tunneling which require workers inside the borehole during the excavation and casing processes [36].

3.1.2.1 Auger Boring

Auger Boring is accomplished with an Auger Boring Machine by jacking a casing pipe through the earth while at the same time removing earth spoil from the casing by means of a rotating auger inside the casing.

The first section of casing pipe may have a steel band welded around the top ¾ of the outside diameter of the pipe. This process, called banding, slightly over excavates the borehole, thereby reducing skin friction on the following casing sections [36].

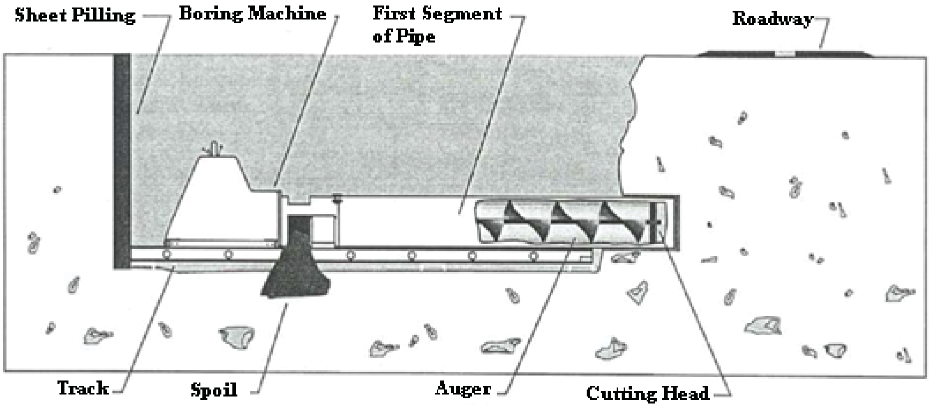


Figure 3.1 Typical auger boring setup [37].

3.1.2.2 Pipe Jacking and Utility Tunneling

A. Pipe Jacking

Pipe jacking is a trenchless technique in which a casing pipe is pushed, or jacked, into the ground, while at the same time; soil is excavated by personnel at the front of the bore. A jacking shield is pushed into the ground, ahead of the following pipe sections. The purpose of the jacking shield is to provide a safe area for workers to perform the excavation at the face (front) of the bore. This excavation may be done manually or mechanically.

Spoil is normally removed from the bore using small carts which are either battery powered, or pulled in and out with a winch. A laser back at the bore pit is set to the appropriate line and grade and shot through the pipe to a target at the front of the bore. Workers can view the laser beam to determine what corrections need to be made [36].

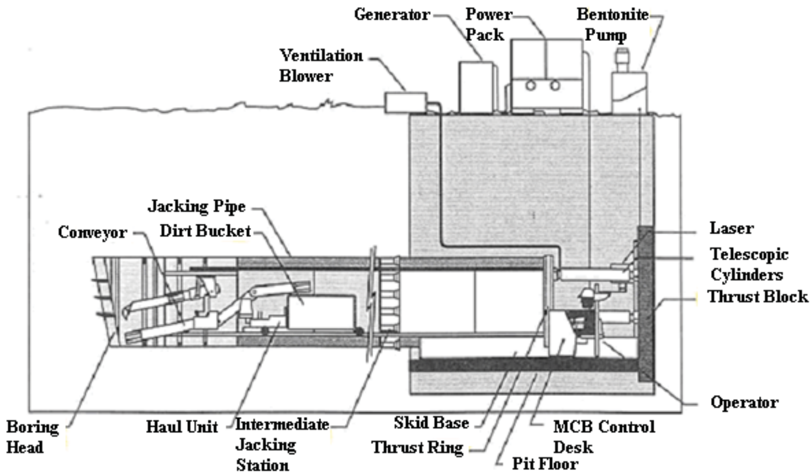


Figure 3.2 Typical component of pipe jacking operation [37].

B. Utility Tunneling

Like pipe jacking, utility tunneling excavation is done inside of a specially designed tunneling shield. The method is differentiated from pipe jacking by the lining installed, and the method of jacking. In pipe jacking, pipe forms the lining of the borehole. In utility tunneling, steel liner plates or rib and lagging form the liner. The liner plates are prefabricated modular units utilized to construct a temporary lining. This temporary lining supports the excavation until it is complete [36].

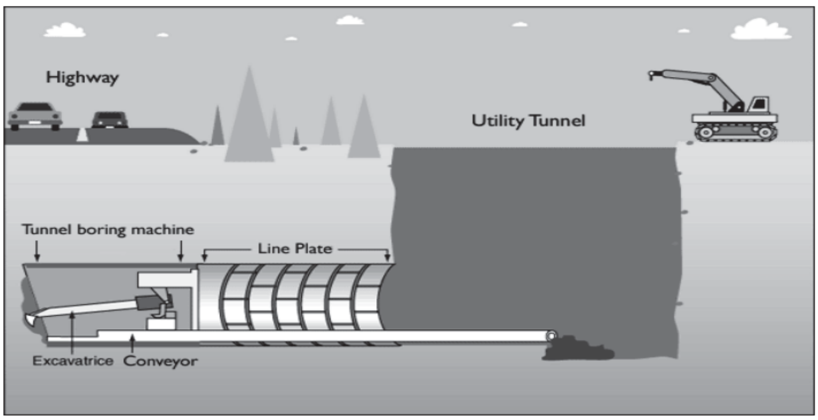


Figure 3.3 Typical utility tunnel installations [38].

3.1.2.3 Micro- Tunneling

The micro-tunneling process is essentially remote controlled pipe jacking. All operations are controlled remotely from the surface, eliminating the necessity for personnel to enter the bore. The excavation is made with a remotely controlled tunnel boring machine. Like pipe jacking, the tunnel boring machine is laser guided and can be steered to maintain the required grade and alignment. The spoil generated can be removed by either mixing the soil with water into slurry or pumping it out of the bore or by removing the spoil with an auger inside a separate auger casing inside the jacking pipe [36].

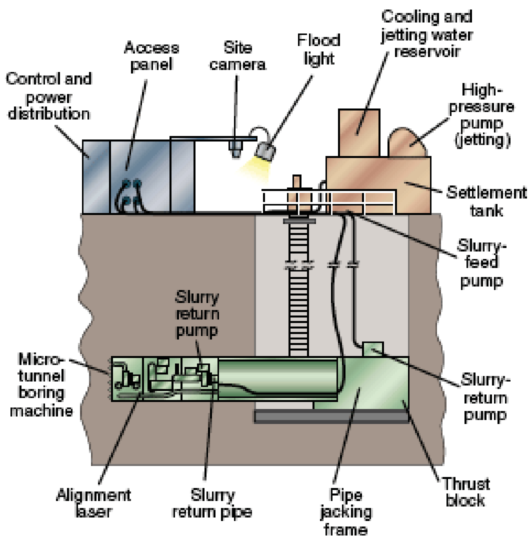


Figure 3.4 Typical micro-tunnel machines [39].

The following table is the summary of various trenchless techniques for new construction.

Table 3.1 Summary of Various Trenchless Techniques for New Construction [36]

Method	Diameter Range (in)	Maximum installation Length(ft)	Pipe Material	Working Requirements	Typical Application	Accuracy/ Tolerances
Auger Boring	4" - 60"	600'	Steel	Entry & Exit pits 26'-36'	Roadways with storm, sanitary sewer, or water main pip	±1% of bore Length
Micro Tunneling	8" and Greater	750'	RCP, GPMP, VCP, DIPI, Steel, PVC, PCP	Jacking pit: 20' long required smaller retrieved pit.	Gravity pipe	±1 inch
Pipe Jacking	42" & Greater	1600'	RCP, GPMP, Steel,	Jacking pit: 10' - 30' long.	Pressure & Gravity pipe	±1 inch
Utility Tunneling	42" & Greater	Unlimited	RCP, GPMP, Steel,	Jacking pit: 10' - 30' long.	Pressure & Gravity pipe	±1 inch

Abbreviations:

DIP: Ductile Iron Pipe; GRP: Glass- Fiber Reinforced Polyester; GPMP: Glass-Fiber Polymer Mortar Pipe; PE: Polyethylene; PVC: Poly-Vinyl Chloride; RCP: Reinforced Concrete Pipe; VCP: Vitrified Clay Pipe.

3.2 Advanced Technologies for Existing Sewer System

3.2.1 Rehabilitation of Sewer System

The techniques used for renewal of deteriorated sewers can be divided into two categories:

3.2.1.1 Non-Structural Rehabilitation

This form of rehabilitation aims to repair deteriorated pipelines by means that prevent further deterioration. A typical example is grout sealing of cracked or leaking sewers [40].

3.2.1.2 Structural Rehabilitation

This typically involves installing a liner that renews the deteriorated pipe's structural and hydraulic capacity.

1. Slip Lining

Slip lining is the simplest technique for renovating man-entry and non-man-entry pipelines. It basically entails pushing or pulling a new pipeline into the old one. Although, in theory, any material can be used for the new pipe, today polyethylene is the most common choice in smaller sizes. The material is abrasion resistant and sufficiently flexible to negotiate minor bends during installation.

Figure 3.5 Slip lining installation [40].

A. Advantages

I- Suitable for a wide range of pipe types and diameters,
II- Relatively cheap simple process.

B. Disadvantages

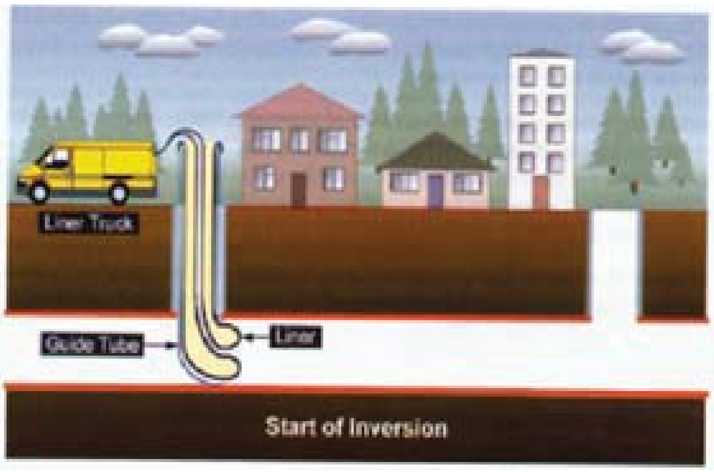
I- Considerable loss of internal diameter,

II- Launch and reception pits must be dug,

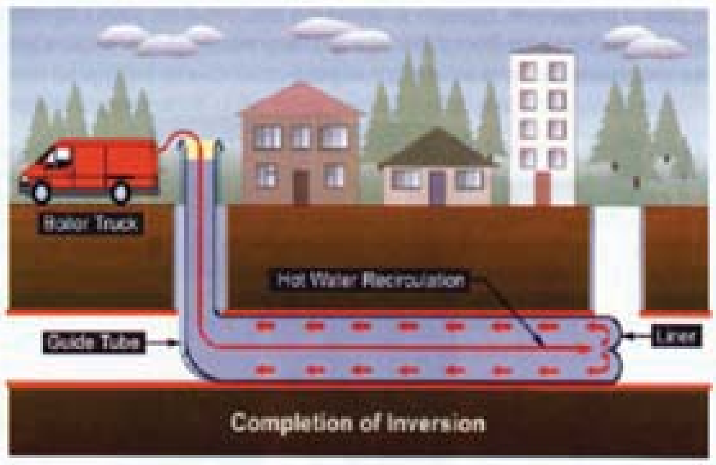
III- Lateral connections must be excavated and re-built.

2. Cured-In-Place Lining

It is sometimes referred to as ‘soft lining’ or ’Cast-in-place-pipe’ (CIPP). The tube is inserted into the existing pipeline and inflated against the pipe wall, then cured most commonly by re- circulating hot water or steam [40].



a. Start of inversion



b. Completion of inversion

Figure 3.6 Installation of CIPP by inversion (both start and completion of inversion) [40].

A. Advantage

I- Close fit liner minimizes loss of pipe bore,
II-Typically installed without digging,
III-Suitable for non-circular shapes,
IV- Handles most pipeline curves.

B. Disadvantages

I- Material properties depend on successful underground curing,
II-Susceptible to wrinkling and cross sectional irregularity if pre-lining repairs insufficient,
III-Bypass pumping usually needed,
IV- Limited ability to accommodate pipe diameter variations.

3. Reverted (Fold-and-Form) Liners

These are “close fit” liners that are deliberately deformed prior to insertion, and then reverted to their original shape once in position so that they fit closely inside the host pipe. Techniques commonly available involve folding the liner into a ‘U’ or ‘C’ shape prior to insertion, and then using heat and/or pressure to restore circularity. Variations are available in polyethylene and PVC for both pressure pipes and gravity sewers. [40].

Figure 3.7 Fold-and-form liners before and after expansion [40].

A. Advantages

I- Close fit liner minimizes loss of pipe bore,

II- Typically installed without digging,

III- Can handle pipeline curves,

IV- Installation may be possible without bypass pumping.

B. Disadvantages

I- Groundwater and infiltration can affect success of liner reversion,

II- Shrinkage can be a problem after installation (particularly for polyethylene liners),

III- Susceptible to cross-sectional irregularities if pre-lining repairs not sufficient.

4. Expanded Spiral Wound Liners

The system consists of a single strip of PVC, which is spirally wound into the existing pipeline via a patented winding machine positioned in the base of an existing access chamber [40].

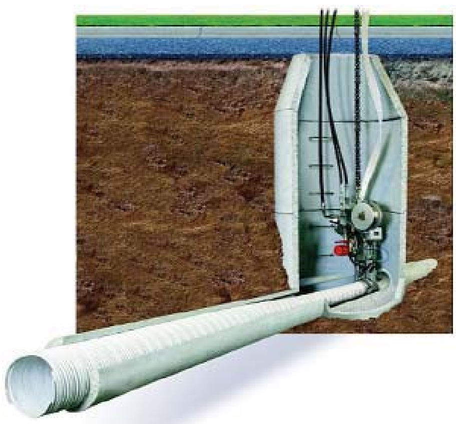


Figure 3.8 Expanda pipes liner installed in the base of a manhole [40].

A. Advantages

I- Assured material properties not dependent on successful curing or heat treatment,

II- Diameter can vary according to the actual diameter of the host pipe, III- Circular cross section with uniform wall thickness. No softening during installation, so does not take shape of deteriorated host pipe,

IV- Faster installation as no heating or curing,

V- Bypass pumping rarely needed,

VI- CCTV monitored during installation,

VII- No shrinkage after installation as no heating is applied.

B. Disadvantages

I- Not suitable for oviform pipes,

II- Limited ability to line around bends.

Table 3.2 Comparison of Rehabilitation Techniques [40].

Item	Rehabilitation				
	Non Structural	Structural			
	Grouting	Slip lining	CIPP	Spiral Wound Lining	Close Fit Liner
Applicable size range (Dia. mm)	Greater than 100mm	Greater than 100mm	Greater than 100mm	Greater than 150mm	150 – 540mm
Required excavation	None	Entry and exit pits at manholes and lateral connections	None	None	None
Required manhole modification	Normally none	Starter pipe and part of benching normally need removal and reinstatement	Normally none	Part of benching at one manhole may need to be broken out and then reinstated for machine access. Lid may need to be removed.	Normally none
Pipe can be installed on a different alignment	No	No	No	No	No
Effect of existing defects in host conduit.	A long term seal will not be able to be achieved if there are structural defects in host such as holes, displaced joints. These should be patched prior to grouting.	Defect that reduce the diameter of the host conduit need to be removed to allow slip lining.	Liner will follow the shape of existing defects, e.g. if there is a displaced joint then there will be a step in the liner. Sharp defects, e.g. protruding laterals should be removed as they could damage the liner during installation.	Liner will follow the shape of existing defects, but smoother transition than CIPP.	Liner will follow the shape of existing defects. Smoother transition than CIPP, but not as smooth as Spiral Wound Lining.
Annulus between host pipe and liner/new pipe	None	20mm. Normally grouted	Nominal	Ribbed profile. For 150mm outside rib annulus is minimal, inside rib annulus is 4mm	Generally less than 1mm
Joints in liner/ new pipe	Existing joints will remain	Welded joints	No joints, continuous liner	Spiral joint along full length of liner	No joints, continuous liner
Time to install (e.g.50m length of pipe manholes)	Less than half a day	Several days. Governed by time to weld pipe and excavate for manhole and lateral connections.	Full day	Less than half a day	Less than half a day
Required working area	At manholes only	At manholes, lateral connections, area to string out, and weld pipe.	At manholes only	At manholes only	At manholes only
Item that affect cost	1- Defects that need to be patched prior to grouting. 2- Access to manholes. 3- Quantity/ continuity of work.	1- Quantity, access, depth and reinstatement requirements at lateral connections. 2- Access, depth a reinstatement requirements at manholes.	1-Amount of lateral connections requiring reinstatement. 2- Access to manholes. 3- Quantity/ continuity of work.	1-Amount of lateral connections requiring reinstatement. 2- Access to manholes. 3- Quantity/ continuity of work.	1- Amount of lateral connections requiring reinstatement. 2- Access to manholes. 3- Quantity/continuity of work.
Specified design life	5-10 years	50 years	50 years	50 years	50 years
By pass pumping required	Not normally	yes	yes	Rarely	Depends on pipe flow
Effect on pipe diameter	None	Pipe diameter reduced by up to 2 nominal sizes (possibly less for large diameter pipes)	Reduced slightly e.g. the diameter of a 150mm pipe is reduced by 9mm. Offset by better hydraulic conditions.	Reduced slightly e.g. the diameter of a 150mm pipe is reduced by 13mm. Offset by better hydraulic conditions.	Varies with process. Similar thickness to CIPP.

3.2.2 Rehabilitation Method for Increasing Flow Velocity and Reducing Sedimentation

3.2.2.1 Modified Sectional Cured in Place Pipe (MSCIPP) Development

Circular concrete pipes are easy to handle and manufacture, but the circular shape has one major drawback. Flow velocity slows when flow quantity is very limited in the dry season. This is the reason for utilizing egg shapes or non-circular sewer systems. Slow flow velocity accelerates sedimentation on the bottom of the combined sewer. More deposit reduces the flow velocity. Sedimentation causes severe problems including reduction in flow capacity and velocity. Reduction in flow capacity may cause combined sewer overflow (CSO) when the rainy season starts [41]. The sedimentation and slow velocity provide an excellent environment for Thiobacillus bacteria that oxidize sulfide to sulfuric acid causing concrete sewer corrosion [42]. The concrete corrosion rate by corrosive bacteria can be more than 5mm per year [43]. Sedimentation and low velocity provide good environmental conditions for hazardous bacterial growth in a combined sewer system. This causes serious potential risks for the public.

A conventional method to increase flow velocity in a circular shape combined sewer is either entirely new construction of a separate sewer system or re-installation of the combined sewer system. A separate sewer system, which carries only sewage and industrial wastewater, has less deposit materials. Most sedimentation components in a combined sewer are derbies carried by storm runoff. Adequate flow velocity is the key to reduce sedimentation in the combined sewer system. When gravity is the only driving force for the circular shape combined sewer system and flow quantity stays constant, only increasing the slope of the sewer can increase flow velocity. A new combined sewer system installation just for increasing sewer slope is an expensive way to reduce sedimentation. Therefore, some companies launched a research program to find an effective method. The research program reduced sedimentation and rehabilitated of the old sewer system [41].

3.2.2.2 Rang of Application

MSCIPP is only applicable where the maximum flow quantity is less than the combined sewer system capacity. In other words, additional design capacity in the current combined sewer system is necessary to apply the modified section of the CIPP on the bottom side of the combined sewer system because the modified section of pipe reduces the existing sewer's flow capacity. MSCIPP is a modification of the CIPP rehabilitation method. It can be applied where CIPP can be installed. Some additional processes are required to install the modified section in the existing pipe [41].

3.2.2.3 Concept and Hydraulic Modeling

Without re-installation of a combined sewer system, the only possible idea was changing the sectional shape of the pipe in order to increase flow velocity. This concept is based on Manning's hydraulic equation. To create the bulge shape in the existing combined sewer, CIPP must be installed above the inflating tube. The inflating tube is later filled by cement mortar and keeps the modified shape permanently. A hydraulic model is developed to find out the most hydraulically efficient shape. Figure 3.9 shows the concept of MSCIPP.

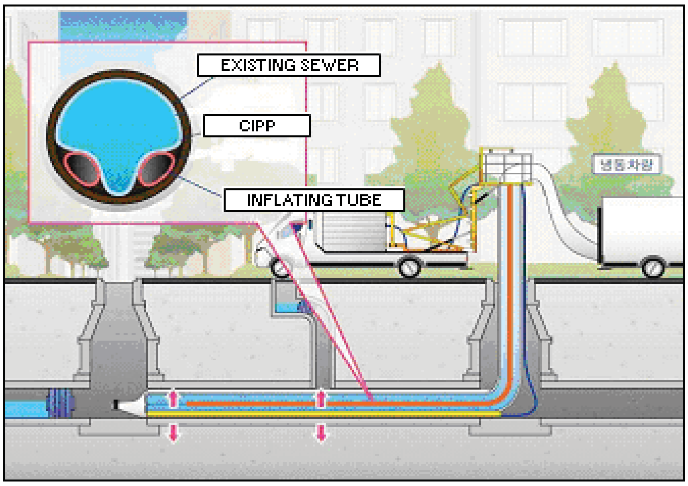


Figure 3.9 Concept of MSCIPP [41].

Several different shapes were tested in the testing bed (Figure 3.10). The hydraulic test was conducted by measuring the velocity and flow depth for each different test shape.

Figure 3.10 Hydraulic model testing bed [41].

There are many empirical equations that can be used to determine the normal depth (y_n) to flow rate relationship for uniform flow conditions.

The general form of the flow velocity equation is expressed as below:

$$V = K\, C\, R^{x}\, S^{y} \tag{3.1}$$

Where,

V: Fluid Velocity, (m/s),

K: Unit Conversions,

C: Roughness Coefficient,

R: Hydraulic Radius, (m),

S: Channel Slope, and

x, y: Fitting Parameters

$$Q = A\, V \tag{3.2}$$

Where,

Q: Fluid Volumetric Flow Rate, and

A = Fluid Cross-Sectional Area of Flow (m^2).

Manning's equation is one of most widely known empirical equation. The test employed Manning's equation for the hydraulic modeling and testing.

$$Q = \frac{1}{n} A \ R^{\frac{2}{3}} \ S^{0.5} \qquad (3.3)$$

$$V = \frac{1}{n} \ R^{\frac{2}{3}} \ S^{0.5} \qquad (3.4)$$

Where,

Q: Flow, (m^3/s),

V: Velocity, (m/s),

A = Area of flow, (m^2),

R = Hydraulic radius (A/P), (m),

n = Roughness Factor, and

S = Slope

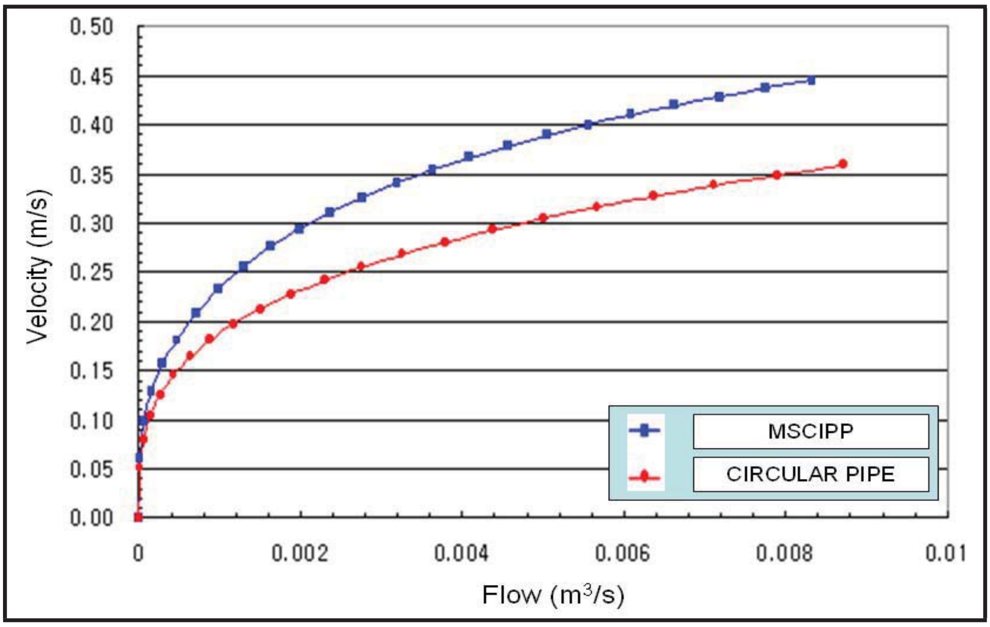


Figure 3.11 Velocity of MSCIPP compared to circular pipe [41].

Figure 3.11 shows testing results comparing flow velocity of a circular shape to a modified shape. Testing bed was built for circular concrete pipe with 400 mm in diameter and 0.1% of slope. The flow velocity was measured then, 45mm inflated rate was applied for modification of pipe sectional shape. Flow velocity increased significantly in most of the flow quantities as much as 30%. Tests were done by applying various dimensions of the pipe, modification, and slope changes. These test results are used as a baseline for building a hydraulic model based on the magnitude of the inflating tube and changes of flow velocity. The hydraulic modeling revealed that a much lower flow quantity was required to achieve the minimum velocity which is usually used to be higher than (0.6m/s) in the modified sections. Manning's equation was used in the model. The hydraulic modeling parameters including slope, hydraulic radius, and sectional area were prepared for reinforced concrete pipe and MSCIPP. A roughness factor 0.013 for concrete was used. Since surface roughness of CIPP is much lower than reinforced concrete pipe surface, the roughness factor should be different. CIPP was assumed as 0.010 [41].

3.2.2.4 Pilot Testing Project and Applications

Ordinary CIPP materials were used for this pilot testing project. After testing various tube materials, high- pressure flexible water tube was selected for the inflating tube. The testing results showed that the high- pressure flexible water tube was the most appropriate material. The high-pressure water tube is cost effective, waterproof, flexible and durable. Cement grouting mortar was chosen as the filling material after inflating the tube. Ordinary cement grouting mortar is cost effective, and easy to work and pump. New methods were developed to make the modified section for MSCIPP. The first method is for medium to small diameter pipe. Two inflating tubes were attached on the outside of the resin-filled felt. Resin-filled felt and attached inflating tubes were inverted simultaneously into the existing pipe. The second method is for larger diameter sewers. Two flexible tubes would be installed on the sewer before inversion process. After the inversion process, air inflates the inflating tube. This inflated space will be filled with cement mortar. Air pressures ranging from 0.5 kg/cm^2 - 2.5 kg/cm^2 were tested. The higher pressure creates the larger inflated space behind of the CIPP. Twenty-four different modified sectional shapes were created and tested in the testing bed. The identification number designates modified section information. For example, a circular section consists of 300mm in diameter size of existing pipe, 65 mm for the installed flexible pipes, 45º degrees to the center point, and inflation rate 55 mm. Figure 3.12 shows the dimensions of a circular section. Figure 3.13 demonstrates various cross sectional shapes modified by different angles and air pressures [41].

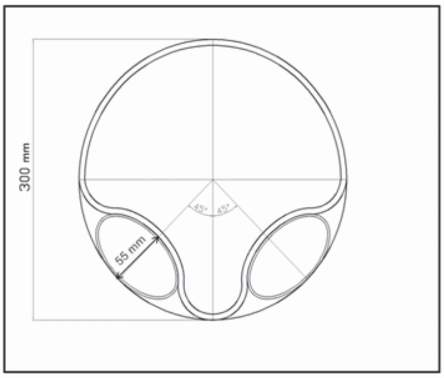


Figure 3.12 Dimensions of a circular section [41].

Angle	Pressure	Cross Sectional View	
30°	0.5kg/㎠		
50°	1.0kg/㎠		
50°	1.5kg/㎠		

Figure 3.13 Cross sectional views of MSCIPP [41].

3.2.3 Inspection of Sewer System

In this section, different advanced technologies were presented for inspection of existing sewer system, among those technologies; laser and sonar profile, robot, and also, flow measurement device.

3.2.3.1 Lasers and Profiling Sonar

The main purposes in using such devices are:

1- Determine the amount of flow discharge in the existing pipe including the accumulation of sediments if existed.
2- Identify and clarify the location of blockages, collapse, and the like.
3- Determining the degree of ovality or deformation inside the pipe [44].

1. Profiling Sonar and Laser: data collection on the float

Using a combination of laser profiling, underwater sonar profiling and high-resolution HDTV imaging collects and processes data on internal pipe line conditions including debris level, ovality, lateral location, and damage without flow diversion, flow interruption, or manhole ring removal [45].

A. Applicability

I- Can be skid, float, or tractor-mounted for both wet and dry pipes.
II- Accurately profiles pipes up to (4m) in diameter

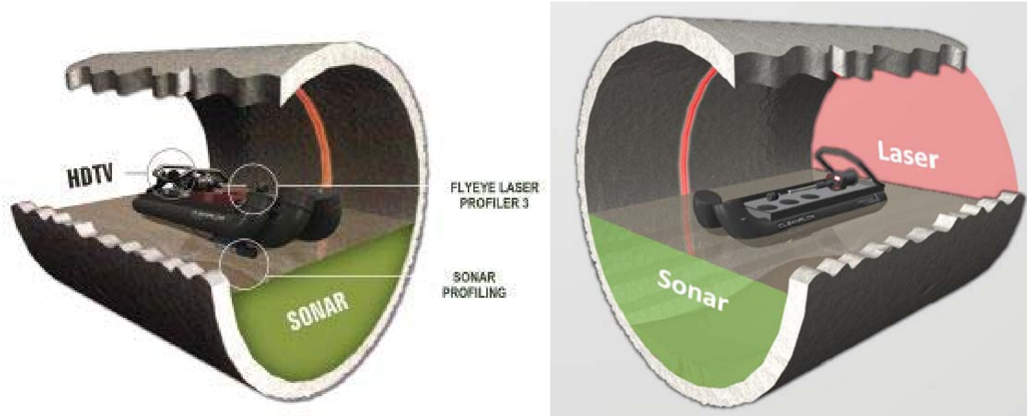


Figure 3.14 Lasers and sonar profiling HDTV [45].

3.2.3.2 Robot (Both Laser & CCTV)

CCTV and laser complement one another - CCTV picks up on the defects the laser is likely to miss, and laser pick up the defects that CCTV operators can't detect or directly measure. Laser can also be used to verify defects observed via CCTV and provide specific physical information on the size and shape of those defects [44].

A. Large Diameter Pipe Inspection System

I- Collects almost 800,000 measurements/minute
II- 3D laser
III- Sonar
IV- H2S gas
V- Temperature
VI- Incline
VII-Digital CCTV.

Figure 3.15 Large diameter pipe inspection systems [44].

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B. Small Diameter Pipe Inspection System

I- On-board power, intelligence, and storage
II- Fully autonomous
III- Lightweight and easy to carry
IV- Inspect with the manhole closed
V- Automatic GPS of manholes
VI- Increased safety
VII- Low carbon footprint
VIII-No dedicated truck required.

Figure 3.16 Small diameter pipe inspection systems [44].

For the purpose of seeing the activities of robots, a visit to some locality for existing sewer system were performed with the maintenance staff in the municipality of Gaziantep-Turkiye in order to see the insertion and capability of robots. Following are pictures showing the shape and size of a certain robot:

Figure 3.17 Shows two types of robot **Figure 3.18** Small robots before insertion

In Figure 3.17, the left hand side robot is used for pipes more than 400mm in diameter and the right hand side is used for pipes less than 400mm in diameter. In fact, the robot that shown in Figures 3.17 is used only for viewing the pipe from inside for the purpose of detection such as; blockage, water seeping, and deteriorated sections in the pipe. Figure 3.20, indicates a detailed image that shows the pipe from inside.

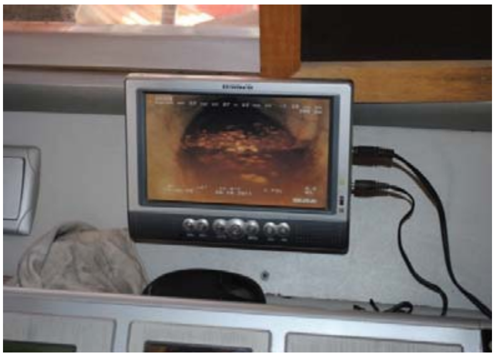


Figure 3.19 Robot about to move. **Figure 3.20** Shows pipe image from inside.

3.2.3.3 Flow Measurement

1. Area-Velocity Flow Monitor (AVFM)

The AVFM uses a submerged ultrasonic sensor to continuously measure both velocity and level in the Chunnel. The sensor is a completely sealed ultrasonic unit with no orifices or ports; it mounts inside a pipe or at the bottom of a rectangular, trapezoidal or egg shaped channel. Working Diameter (15-75cm) [46]

Figure 3.21 Area velocity flow monitor (AVFM) device [46].

3.2.4 Sewer System Cleaning Equipments

Pipeline cleaning and maintenance methods depend on the wastewater characteristics, fluctuations in flows, sewer alignment and grade, pipe material, condition of the sewer, and the type of area being served. Blockages can be cleared or prevented and sewers cleaned by either hydraulic or mechanical methods. Hydraulic methods consist of cleaning sewers with water under pressure that produces high water velocities. These velocities are usually high enough to break up the blockage and flush most grit, grease, and debris. Mechanical methods consist of using equipment that scrapes, cuts, pulls or pushes the material out of the pipeline [47].

1. Flushing Nozzle

It is a heavy vibration nozzle capable of providing the maximum break up effectiveness and use a larger diameter line.

Figure 3.22 Flushing nozzles in sewer system [48].

A. Applications

I- Large line deposits break up, pulverize, disintegrate, and flush. Not to be used in clay or stone pipe.

II- Working diameter (30- 90 cm) [48].

2- Flushing jet

Other common flushing equipments are flushing jet, which is close to vibration nozzles. During visit to some locality for existing sewer system in Gaziantep-Turkiye with maintenance staff, it is observed that, in case of having blockage locations, the pipe is cleaned with water under pressure using flushing jet wagon, and then, the debris is sucked by 4" hose pipe using the same wagon, of course if the debris particles is less than 4". Figure 3.23 indicates flushing jet wagon.

Figure 3.23 Shows flushing jet wagon.

3. Milling System

The Milling System utilizes an internal gearing system to generate torque to the milling head which is capable of cutting concrete, major mineral deposits, and solid blockages.

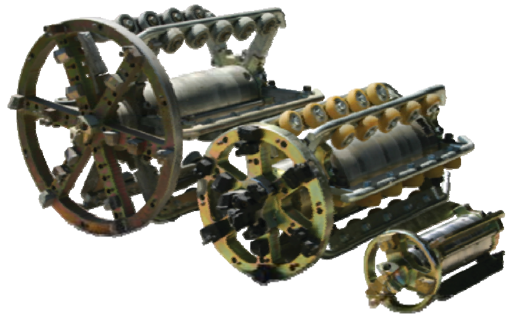


Figure3.24 Milling system equipment [48].

A. Applications

I- Removal of concrete and major mineral deposits.
II- Working diameter (30-60 cm).

4. Curved Blade Cutter

Curved Blade Cutter with Three Blades, this heavy duty cutter with replaceable steel blades (1/8" thick and 1-1/4" wide) does a good job on roots and an even better job on grease. This heavy duty cutter will scour the pipe razor clean, working Diameter up to 45cm.

Figure 3.25 Curved Blade Cutters [48].

5. Rotor- Nozzles

This state of the art development among rotation nozzles is independently driven, regardless of pressure and volume stream, with a rotation rate between 50 and 300 rotations per minute, working Diameter up to 3m.

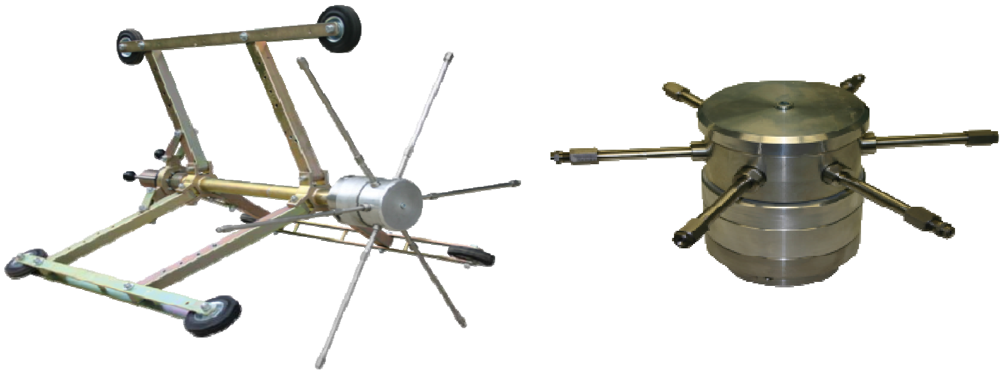


Figure 3.26 Rotter- nozzles in sewer system [48].

3.3 Comments

3.3.1 Trenchless Technologies

Using Trenchless technologies may not consume times during working, in comparison with the classic digging (open trench excavation), also does not harm the surrounding area. As explained previously, the use of such technologies may differ from soil type to another, in cases of having poor soil condition; casing or shielding may be a significant solution during drilling (this is what has been discussed during communication with geotechnical division in engineering faculty-University of Gaziantep-Turkiye.

In fact, during communications with some foreign companies to get more details about trenchless equipments such as; price, working limitations, and equipment types, unfortunately, no response received from these companies. Therefore, the writer thinks that, there is still more investigations suppose to be performed in order to clarify and distinguish the applicability and feasibility of such technologies along with optimized cost.

3.3.2 Rehabilitation Suitability

Clearly rehabilitation of sewer by lining is not applicable where the existing pipe needs to be realigned, upsized or contains dips or multiple faults such as displaced joints. However, for most circumstances lining by Cured in Place Lining, Reverted Liners or Spiral Wound Liners is appropriate. The different methods have their own advantages and disadvantages. Some techniques such as Expanded Spiral Wound Liners are quicker to install and less disruptive than others, whilst techniques such as Cured in Place Lining may be more suitable for infiltration reduction because of there being only a nominal annulus between the liner and the host pipe. All lining techniques, if properly installed, will provide a good long-term structural solution. The decision as to what technique to use therefore comes down to lowest cost and the contactor's expertise and quality assurance procedures [40].

3.3.3 Pilot Test (MSCIPP) Evaluation

Pilot testing evaluation concluded that MSCIPP was a successful program and would be worth testing in a real rehabilitation project. Flow velocity was increased higher than 20% by modifying the section of a combined sewer. MSCIPP can reduce the rate of sedimentation effectively in a combined sewer without reinstallation of the sewer system. MSCIPP can be a good solution for a combined sewer system rehabilitation project if the existing sewer system has a low flow velocity problem. A few things should be improved for increasing the productivity of field installation. Special equipment including a specialized lateral connection robot is currently developing. There are some ideas for utilizing inflated space instead of filling the cement mortar. Inserting a small diameter pipe in the modified section for communication lines including high speed Internet and fiber optic line will be a good way to maximize the efficiency of underground infrastructure. More research efforts are required to improve current sewer system rehabilitation application [41].

3.3.4 Cleaning Equipments

During investigating different devices and equipments that used for sewer system maintenance, it appeared that the need to use such technologies has become essential due to their significant processing. Nowadays, applying these advanced technologies may offer a great benefit to the municipalities by the way that:

A- Increase laborsaving,
B- Decrease consuming time,
C- Decreasing excavation work,
D- Protecting work location from being dirtied,
E- Keep the location noiseless (no excavation work),
F- Protect the pedestrians and cars from sudden falls (in case of having open trench),
G- Saving cost as a long term solution.

So, it is value to note that these advanced technologies have alleged advantages when compare it with classic maintenance processing in the term of optimized cost (long term processing).

3.3.5 Advanced Technologies in Developing Countries

Despite the existence of advanced techniques, unfortunately, most developing countries are still suffering from severe sewer system problems either due to not having any sewer system at all, or, because of the inefficiency of the existing sewer system and/or due to the lack of efficient operation and maintenance.

3.3.5.1 The Factors Influencing the Applicability of Advanced Technologies

In developing countries, the main reasons that make the use of advanced technologies impractical or inapplicable are:

A- The lack of existing infrastructure plans and/or sketches.
B- The lack of having sufficient skills for applying these advanced technologies.
C- The lack of sufficient financial support and/or due to the poor administration.
D- The lack of coordination and exchange of expertise among different municipalities within the country in concern regarding the implementation of ordinary projects and/or advanced technologies.
E- Frequently, the authoritative personnel are political rather than being technical.

F- One of the essential factors that make the cost of advanced technologies being unaffordable is the insistence of the relevant companies to complete the works fully without the implementation/help of the regional municipality, even for the simple works such as excavation and the like.

G- Lack of serious penalties against those users who abuse the system.

H- Lack of providing advanced courses and scholarships for engineers and technician regarding advanced technologies.

The communications with municipalities of more than one country revealed that such implementations were limited. Specifically, the Lining System, Trenchless System, and the computerized SCADA control system (Supervisory Control and Data Acquisition) were not considered for application, mainly due to their high cost. However, the flow measurement by laser and other methods, along with the use of robots for viewing the pipes from the inside were implemented by some municipalities.

CHAPTER 4

SEWER PIPE CROSS SECTIONS

4.1 Sewer Pipe Characteristics

A- Can come in many different shapes.
B- Have many different features.
C- Several different materials can also be used. [1]

4.2 Structure Requirements in Sewer Pipe

Structurally, closed conduits must resist a number of different forces singly or in combination:

A- Internal pressure equal to the part/full head of liquid to which the conduit can be subjected;
B- Increased internal pressure caused by sudden reduction in the velocity of the liquid;
C- External loads in the form of backfill and traffic: and
D- Temperature- induced expansion and contraction. [49]

4.3 Selection of Pipe Cross Section

A- The selection of cross-section of sewer depends on the;
B- Efficiency of flow (hydraulic mean depth and roughness of materials),
C- Structural stability,
D- Cost,
E- Convenience in maintenance and operation, and
F- Resistance to internal and external pressures.

4.4 Previous Studies on Sewer Cross Sections

4.4.1 Circular and Egg-Shaped Pipe Cross Section

The egg- shape shown in Fig 4.1 was introduced in England by Mr. John Philips in 1846, and is used today with the same properties than advised.

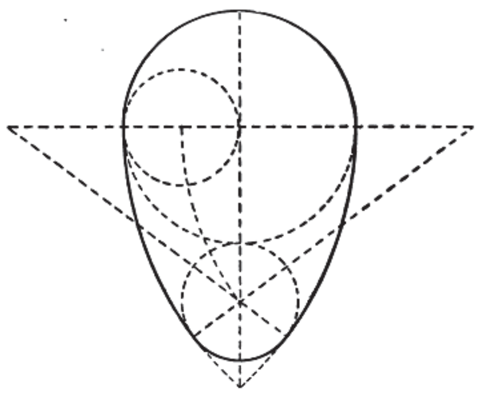


Figure 4.1 Egg-shaped cross section (invert Radius 1/4 transverse diameters) [50].

The vertical height is equal to one and a half times, the radius of invert is equal to one fourth, and the radius of the side to one and a half times the transverse diameter. The other form of Egg-Shape, Figure 4.2, has a smaller invert and is therefore better adapted to sewer where the depth of flow may at times be very small.

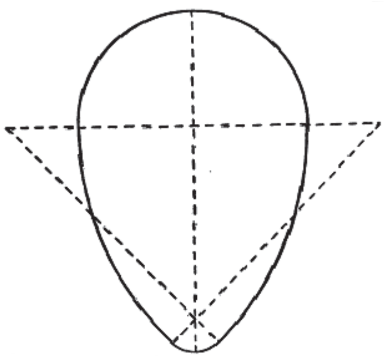


Figure 4.2 Egg-shaped cross section (invert radius 1/8 transverse diameters) [50].

The vertical times the transverse diameter as before. The radius of invert is one eighth of transverse diameter and the radius of the sides one and a third times. Latham says that this new form is stronger than the old, and that with small volumes of flow it is better adapted to be self-cleansing that earlier form.

Other forms given by Latham and other engineers; some wide and shallow, designed chiefly for place where head room is restricted, as under streams or railroads, while others deep and narrow are used to advantages in deep trenches where the excavation is made from the surface [50, 51].

In order to obtain some comparison between the value of egg shaped and circular sewers when the flow is small, the author has plotted two sections, reduced in Figure 4.3, one of a circular sewer 6 feet in diameter showing depths of flow of 3, 6, 12, and 24 inches, and one of an Egg-Shape, with the same discharges in both cases.

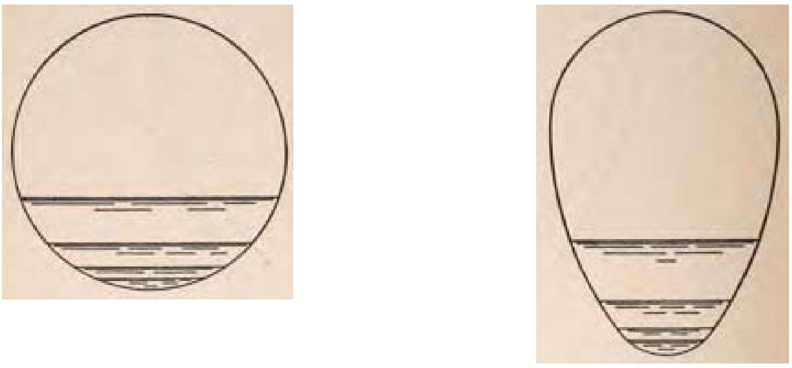


Figure 4.3 Circular sewer of 6 feet and an egg-shape sewer pipe [50].

The slope was assumed at 0.03 percent for both sections, and by repeated trials the depths in the Egg-Shape necessary to give the same discharges as the Circular were found. The benefit then seen in the increased value of V in the former case. Table 4.1 shows comparison between the value of egg shape and circular sewer.

Table 4.1 Comparison between the Value of Egg-Shape and Circular Sewer [50]

Item	Circular Sewer				Egg-Shape			
	I	II	III	IV	I	II	III	IV
Depth	0.35	0.5	1	2	0.32	0.58	1.2	3.87
Area	0.41	1.12	3.11	7.24	0.37	0.87	2.08	7.04
"C"	0.56	0.66	0.86	0.97	0.64	0.73	0.82	0.96
Discharge	0.16	0.64	3.53	12	0.18	0.63	3.2	11.32
Velocity	0.39	0.56	1.14	1.66	0.50	0.73	1.48	1.63
Percent gain in velocity					0.28	0.30	0.30	…….

According to table 4.1, again of about 30 percent in the velocity is obtained by using the Egg-Shaped sewer.

4.4.2 Egg-Shaped, Circular, and Non-Circular Pipes

Sewers built in older times had been developed in a variety of shapes. Carson et al. (1894) described, as an example, the pipe handle cross-section (similar to a horse-shoe cross-section with vertical intermediate walls and semi-circular soffit), the gothic section with a pointed arch and the egg-shaped cross section besides the circular cross-section.

French (1915) compared the above mentioned four sections regarding the velocities by application of Kutter's formula for equal discharge. The egg-shaped section was identified as the best capacity cross-section up to 35% part-full flow and for larger flow depths all sections are hydraulically similar within 5%. Overall, the circular section performs best. The egg-shaped section shows in service more deposition than the corresponding circular section.

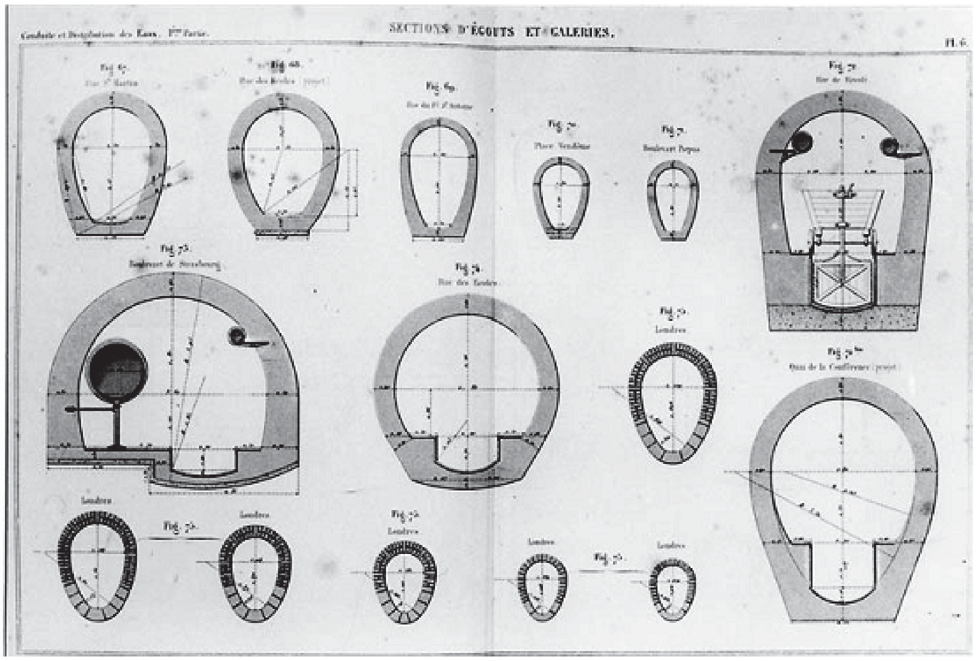


Figure 4.4 Cross-Sections of Sewers Used in the City of Paris, after Dupuit (1854) [52].

Donkin (1937) compared the circular with the egg-shaped and the U-shaped sections both hydraulically and economically. The U-shaped section constructed in brick stone was found to be narrowly optimum compared to the other two sections. The techniques used in these investigations may not be considered sufficient in current standards.

Thormann (1941) introduced the standardization of cross-sectional types of sewers. Fifteen cross-sections were proposed all of which are axis-symmetric and either egg-shaped or horseshoe shaped. Denoting the width of the section as B and the height from invert to soffit T, six different axis ratios B: T = 2: αp were proposed, with αp = 3.5, 3, 2.5, 2, 1.5 and 1. The cross-sectional forms include:

A- Extra-high, normal, transposed, depressed and transposed-depressed egg-shaped sections,

B- Extra-high and normal circular sections,

C- Cap- or hood-shaped cross-section with αp = 2.5 and 2, D- Parabolic cross-section 2:2,

E- Kite-shaped cross-section 2:2, and

F- Horseshoe-shaped cross-sections for αp = 1.5 and 1.

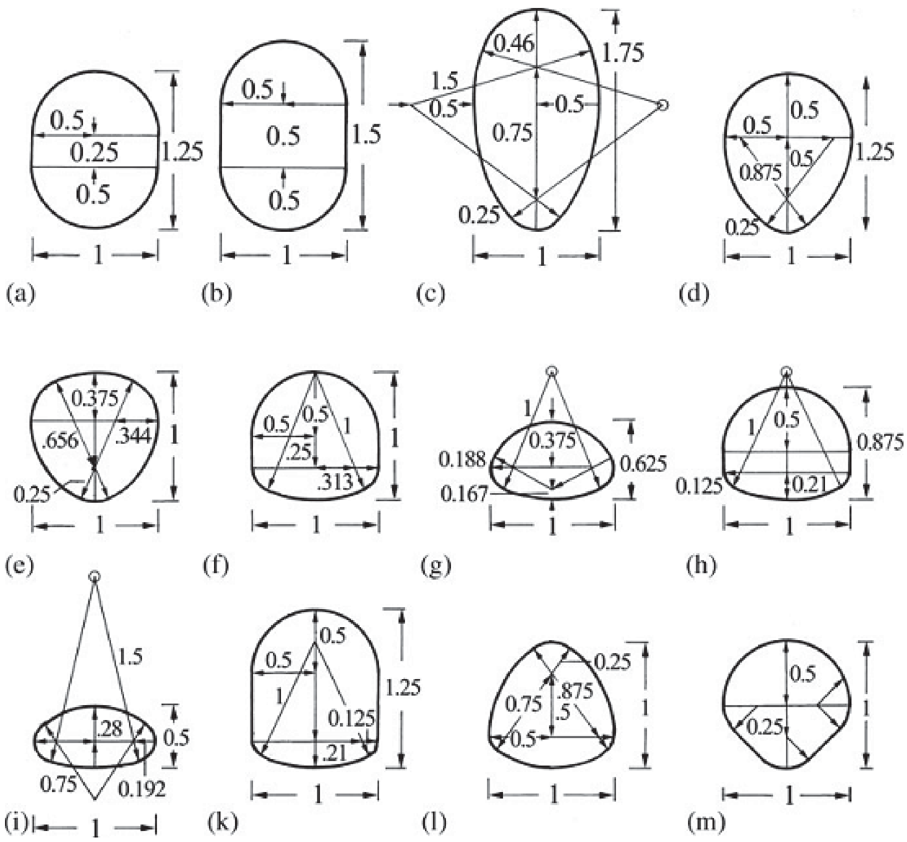


Figure 4.5 Non-standard sewer profiles with unit width B = 1, and fractions for other lengths (ATV 1988) [52].

These cross-sections form the basis of ATV 110 (1988). The standard construction technique for the cross-sections was established by Schoenefeldt et al. (1943).

Thormann (1944) defined the cross-sectional geometry of fifteen standard sections, Roske (1958) referred to the dimensionless representation of the cross-sectional sizes only to the circular, the egg-shaped and the horseshoe-shaped sections.

Kuhn (1976) concluded that neither the circular nor the egg-shaped nor the horse-shoe sections possess definite advantage over the other sections recommended, so that no general recommendation can be given. Because of the industrial finish technique the circular cross-section is employed in a wide variety of situations for which the section is often referred to as the standard sewer cross-section.

Schmidt (1976) compared the standard egg-shaped section with the circular section. For the same cross-sectional area the relation between the diameter DE of the normal 2:3 egg-shaped section and the diameter Dk of the circular section is given by Dk = 1.2DE. As long as the discharge is $Q/Qv \leq 0.22$, the velocity in the egg-shaped section is higher than that in the corresponding equal area circular section. It is stated that for a night minimum discharge of around 1% of the storm water flow, around 7% part-full stage establishes in the egg-shaped section while it is only about 4% in the circular section. To produce the same velocity, the circular section would require about 30% more bottom slope than the egg-shaped section. According to Schmidt (1976), the standard egg-shaped section is suited for slopes which are unfavorably placed with regard to the avoidance of deposition during dry weather flow.

Sartor and Weber (1990) followed the opinion of Schmidt and recommended specially the egg-shaped section because of its advantages in maintenance and water quality.

A quantification of these advantages requires comparative accounting of the pollutions carried by the sewers. Egg-shaped sections having cross-sectional dimensions smaller than 500/750 are of special interest.

According to ATV (1988) the standard cross-sections are:

A- Circular section,
B- Egg-shaped section 2:3, and
C- Horseshoe section 2:1.5.

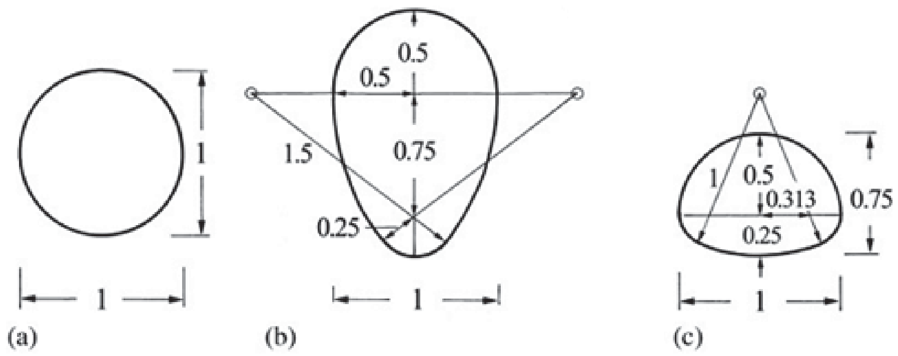


Figure 4.6 Standard sewer profiles based on unit width B = 1. (a) Circular sewer, (b) Egg-shaped sewer 2:3, (c) Horseshoe sewer 2:1.5 [52].

The remaining twelve cross-sectional forms, standardized by Thormann referred to previously, can be alternatively described with the part-full flow characteristic curves of their normalized sections. For the determination of the full flow quantities, the so-called form factor must be known. The form factor describes the influence of cross-sectional geometry on the discharge. What the relevant reports in the literature do not state is whether in the future only the three standard sections have to be considered. Having this in mind, only the circular section is usually considered herein. On questions of sewer flow, the standardized egg-shaped and the horseshoe sections are also accounted for. Pecher et al. (1991) follow this treatment also, whereas Unger (1988) considers solely the circular and the standard egg-shaped sections [52].

B.C. Punmia (1998) classified sewer pipe cross section in to:

4.4.2.1 Circular Cross Sections

Sewers of circular cross-section are more commonly used because of the following advantages:

A- Circular sewers are easily manufactured.

B- A circular sewer gives the maximum area for a given perimeter and thus gives the greatest hydraulic mean depth H.M.D. when running full or half full. It is therefore the most efficient section at these flow conditions.

C- It is the most economical section since it utilizes minimum quantities of the material.
D- Circular section has uniform curvature all around and hence it offers less opportunity for deposits [53].

4.4.2.2 Non-Circular Cross Sections

The following are the non-circular shapes, which are commonly, used for sewers [3].

A. Basket hand Section

In this type of sewer, the upper portion of sewer has got the shape of a basket-handle as shown in figure 4.7. The bottom portion is narrower and carries small discharges during monsoon and combined sewage is carried through the full section. This shape of sewer is not generally used at present.

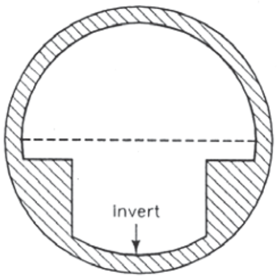


Figure 4.7 Basket-handle cross section [3].

B. Egg-Shaped or Ovoid Section

This type of sewer is suitable for carrying combined flow. The main advantage of this type of sewer is that it gives slightly higher velocity during low flow than a circular sewer of the same capacity. But construction of this section is difficult and less stable than circular section. Inverted egg-shaped sewer gives better stability and carries heavy discharges. The details are as shown in figure 4.8.

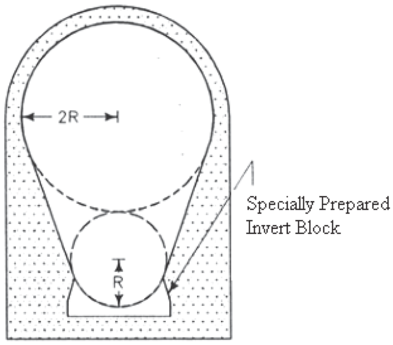


Figure 4.8 Standard egg-shaped cross section [3].

C. Horse-Shoe Section

This type of sewers is used for the construction in tunnel to carry heavy discharges, such as truck and outfall sewers. This is also suitable when the available headroom for the construction of sewer is limited. The invert of the sewer may be flat, circular or parabolic and top is semi-circular with sides vertical or inclined as shown in Figure 4.9.

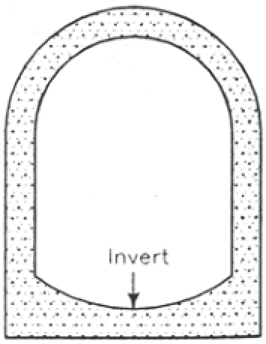


Figure 4.9 Horse shoe cross section [3].

D. Parabolic Section

This type of sewers is suitable for carrying comparatively small quantities of sewage and economical in construction. The invert of sewer may be flat or parabolic and upper arch of the sewer takes the form of parabola as shown in Figure 4.10.

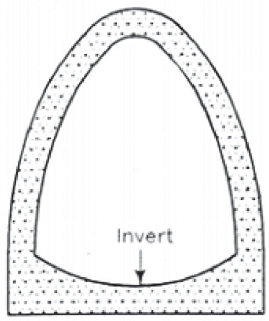


Figure 4.10 Parabolic cross section [3].

E. Semi-Circular Section

This type of sewers is suitable for constructing large sewers with less available headroom and it possess better hydraulic properties as shown in Figure 4.11.

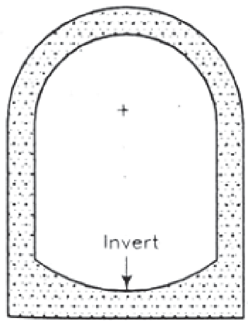


Figure 4.11 Semi circular cross section [3].

F. Semi-Elliptical Section

This type of the section is suitable to carry heavy discharges and adopted for soft soil, as it is more stable. The diameter of sewer may be more than 1.8m and possess good hydraulic properties except at low depths as shown in Figure 4.12.

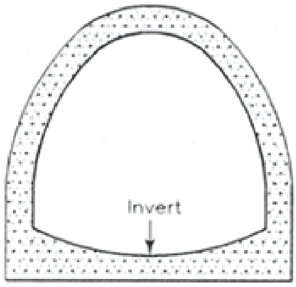
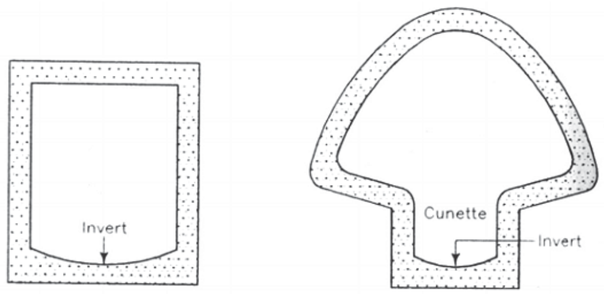


Figure 4.12 Semi elliptical cross section [3].

G. U- Shaped Section:

The shape of this section is the true shape of letter U as shown in Figure 4.13.A. Or small trench of U shape can be setup in the larger section of sewer as shown in Figure 4.13.B. The trench is known as the Cunette and adopted for a combined sewer having predominant flow of storm water.

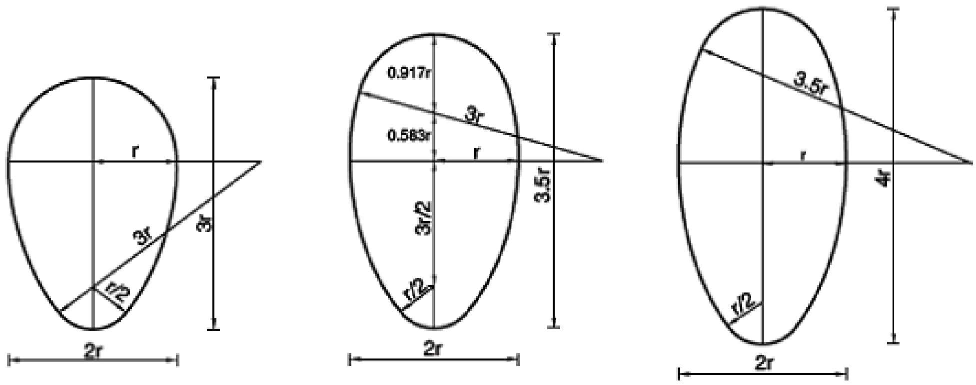


A. U- Shaped Section **B.** U-Shaped Section with Cunette

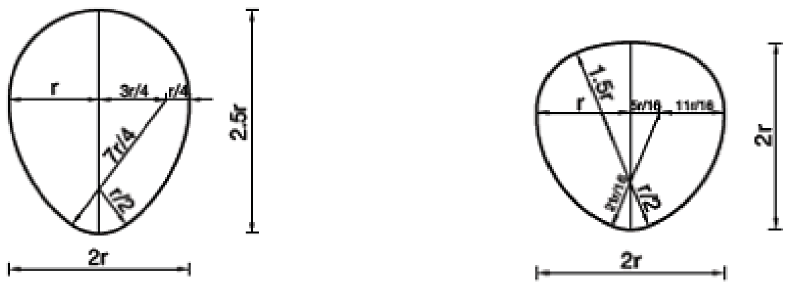
Figure 4.13 U- Shaped cross section [3].

All of the non-circular shapes (explained previously), except the ovoid sections (Egg Shapes) and Rectangular section; have practically become obsolete because of the difficulty in their construction and because of non-availability of factory made sections of these shapes. However, ovoid shaped sewers are still in use as combined sewers. In the combined system, the discharge is subject to great variation. The sewer is heavily taxed in the rainy season while the D.W.F. during the summer may not be even [5 to 10%] of the combined sewer. Hence the circular sewer, if provided for the combined sewer system, will run with very low depths. In such circumstances, ovoid sewers are more suitable. Its main advantages are that gives slightly higher velocity during low flow than a circular sewer of the same capacity. Rectangular sections are mainly used as independent covered storm water surface drain rather that as sewers [53].

Currently, different egg shape sections have been produced [54]. Figure 4.14 indicates five types of egg shapes:



A. Egg-Shape 2:3 **B.** Egg-Shape 2:3.5 **C.** Egg-Shape 2:4



D. Egg-Shape 2:2.5 **E.** Egg-Shape 2:2

Figure 4.14 Egg-shaped sections of different dimension [54].

The selection among different egg shape sections has been explained in chapter 5.

4.5 Comments

Different forms of sewer pipes have been used in previous decades, where some were used for storm water drain and others for sewage liquid or for both. So, their studies were concentrated on various shapes of pipe in order to clarify the functions of each one and the purpose that used for. Thus, in the latter, it is noted that the most common shape among non-circular pipes are both egg/ovoid section which is used as combined or separate sewer system (sanitary system) and the rectangular (box section) for storm water drain.

Recently, some companies produced the standard egg-shape (2:3) for sanitary use and other non-circular pipes like arch shape, and elliptical shape as a storm sewer collector. Obviously, the need for using pipes that have wide and shallow size such as; rectangular, elliptical, and arch shape for storm water may give significant benefit if the design discharge are used to be heavy that needs to have sufficient volume.

Generally, the main problem in sewer system (separate and combined) is that when the liquid velocity reduced less than the required limit, the sedimentations start to settle in the pipe causing blockage, this is why most scientist described the egg-shaped pipe as an alternative instead of circular pipe despite of being difficult in construction and its cost is relatively high.

In fact, all the scientist opinions say that the egg-shape has significant advantages in flow velocity over the circular pipe, some others say that the egg-shape has slightly higher velocity without mentioning how much or is it alleged to use or not. The only scientist who performed numerical calculations between circular and egg-shape was Ogden (explained previously), where the results indicated that the egg-shape has 30% higher velocity over the circular pipe for low flow conditions. However, his assumptions depend on two conditions which are;

1- Same/or approximate discharge assumed for both circular and egg-shape pipe during calculations,
2- Same slope used for both pipe (circular and egg-shape).

On the other hand, the egg-shape pipe diameter assumed to be a certain value without explaining numerical dimensions, and also the formula that used for calculation was unclear, where the factor “C” in each pipe had a different value. Therefore, in chapter 5, investigation among circular shape, egg-shape, and other non-circular pipes have been performed, and the results numerically investigated in order to find out the hydraulic characteristics among non-circular pipes in comparison with circular one.

CHAPTER 5

COMPARISON BETWEEN CIRCULAR AND NON- CIRCULAR CROSS SECTIONS

The main advantage of circular pipe over the non-circular ones lies in the fact that when being half full, or nearly full, there is a relatively greater velocity for the same slope. From the geometric point of view, for the same perimeter the circle, of all polygons, has greatest area, and consequently, the least cost for construction. However, with relatively low flows, the circular section appears not to be the best section. The lower the flow is the more friction would be expected in relation to the flow cross section, and consequently, the lower velocity. The latter is the main disadvantage which would give sediment more chance to settle. This could be easily observed through Manning equation as explained previously in Chapter 3.

In a sewer pipes where the depth of flow varies with time towards the end of the day, the velocity decreases as depth decreases, due to the decrease of the hydraulic radius. With relatively low flows, it is always preferred to have a velocity that is high enough to reach the self cleansing level. This shows the need to investigate various sewer cross sections in order to compare and search for the optimum section. In this chapter, numerical and graphical investigation was performed in order to indicate the sensitive differences between the circular and non-circular cross sections.

5.1 Principles for the Comparison between Circular and Non-circular Pipes

The principle of the comparison starts with selection of three different diameters of a circular cross section (0.3, 0.8, and 1.5m) respectively, each circular pipe compared with four shapes of non circular cross sections of different dimension. The reason behind selecting these diameters is that, they are the closest and the most common pipes used for the time being by the designers.

The reasons behind the selection of the four non-circular shapes for comparison among the available variety of non-circular shapes proposed by previous researchers are explained in the following section.

In order to make the comparison between the behavior of the circular and non-circular section more realistic and specific, special attention was given to the need to establish clear principles that are based on the following:

1- Safety regarding the degree of the probability of the variation in flow and its influence regarding the fullness ratio in the relevant cross section.
2- Equality of the flowing discharge in the different sections.
3- Equality in using the same formula during all calculations.
4- Cost of the excavation.
5- Cost of pipe.

These principles are as follows:

A- For all pipes of all proposed cross sections, the Manning Coefficient was selected to be n = 0.013. This is due to the fact that the research is an application on projects that are executed in urban regions rather than rural ones, where cement pipes are most common in developing countries. In fact, only recently, the PVC pipes started to have a competitive position in the markets of those regions due to its easy manufacturing and flexibility. Despite that Manning Coefficient for the PVC pipe is recommended to be n = 0.01, the general tendency of the observation and results of the computations in the research should not be any different from those obtained for n = 0.013.

B- The height between water surface and the crown of the pipe in concern should be sufficient to enable for probable flow fluctuation or the occurrence of waves without causing the flow to be full/pressurized. This height, which results from the fullness ratio, is usually determined according to the diameter. The larger the pipe is the larger this ratio could be. During the comparison process, it was considered that the empty height above water surface in non-circular sections should be either equal or larger than the one found in the circular one. It is impossible to keep that height equal during the variation of the flow in the section chosen for comparison because of the difference in shape.

C- For the circular pipe section, three diameters were selected to represent the variation between the relatively small group, the medium, and the large one. These diameters are 0.3, 0.8, and 1.5m.

D- The maximum fullness ratio selected for the pipes explained in the previous paragraph are considered to be 50% for 0.3m, 70% for 0.8m, and 80% for 1.5m. These fullness ratios were taken from the recommended table for the design in Water Supply and Sewerage of Gaziantep (GASKİ).

E- In circular pipes, the values of the varying discharge, relevant to each of the three chosen fullness ratios related to the specific relevant pipe diameter, were calculated and registered starting from 5% fullness ratio with increasing steps of 5% up till the maximum level allowed. These very same recorded values of the increasing discharge were applied on each of the non-circular pipes for comparison. However, using the same discharge stages in both circular and non-circular pipes during the different attempts does not necessarily produce the same fullness ratio for the maximum discharge.

F- In circular pipes, with the consideration that a term called area ratio a/A where a is the area of flow cross section, and A the pipe total cross section. This ratio is recorded during the comparison process throughout all attempts. Due to the different configurations in non-circular sections, it appeared essential to have their area ratio either equal or less than what has been recorded in the circular section, obviously, while keeping the values of the slope and discharge the same.

G- In order to make the comparison more realistic, the size of the different shapes of the non-circular section were selected on the basis that would give the closest area ratio to that obtained from the circular shape without exceeding the latter value. Moreover, the selected dimensions of the non-circular sections were taken with applicable round numbers, which is more applicable for the industrial sector.

H- For the comparison purpose, it is thought to vary the slope in a way to represent three groups of the relatively gentle, average, and relatively steep. The very steep was not taken into consideration, simply because there will be no need for non-circular pipes in such case, and the velocity in circular pipes would be satisfactory. These representative slope values are selected to be 0.001, 0.003, and 0.006.

I- Each pipe diameter was studied regarding each of the three slopes independently. Three diameters and three slopes resulted in nine attempts for comparison.

J- Each attempt of the nine explained in the previous paragraph represents a comparison between the flow behavior of the selected circular pipe and the relevant selected non-circular group of pipes (a total of 4 selected shapes). Each of these attempts aimed to observe the flow behavior with the consideration of a varying flow in the circular pipe from 5% fullness ratio to the maximum allowed as explained in paragraphs C and D. The selected non-circular pipes, along with the reason for the selection are presented in the section 5.3.

5.2 Strategy for the Comparison Process

Following the principles and assumption explained in the previous section, the way the comparison should be performed had to be of an equal importance and sensitivity. The comparison was planned to be observed from different point of view. In other words, it is thought to link the variables involved in the process in more than one way with the hope that if one method does not show clearly evidence of the difference in behavior, the other/s are likely to do the job.

The plan for the calculations and for drawing the results of the calculations is thought to be as follows:

A- Compare the discharge with the flow velocity ratio V_e/V_c, where V_e is the velocity of non-circular pipes, and V_c is the velocity for circular ones. Here, it is essential to state that the discharge in circular pipe repeated for each diameter and for each slope, were recorded for each step of the fullness ratio starting from 5% to the maximum proposed. Then, these same recorded values were applied in the calculation for the non-circular section. Accordingly, these resultant velocities in the non-circular section were plotted for comparison with the circular velocities. This is followed in all other methods of comparison between the circular and non-circular sections, which are explained below.

B- Compare the discharge with the flow velocity of all circular and non-circular sections.

C- Compare the fullness ratio with the flow velocity of all circular and non-circular sections

After completing these calculation and plots, it is thought that the previously explained three groups of plots (nine for each group) performed for comparison could be presented in a 3-D plot, in order to show any probable link between the different variables. This resulted in 9 more 3-D Figures.

The plan for work could be represented in a simple sketch as shown in Figure 5.1

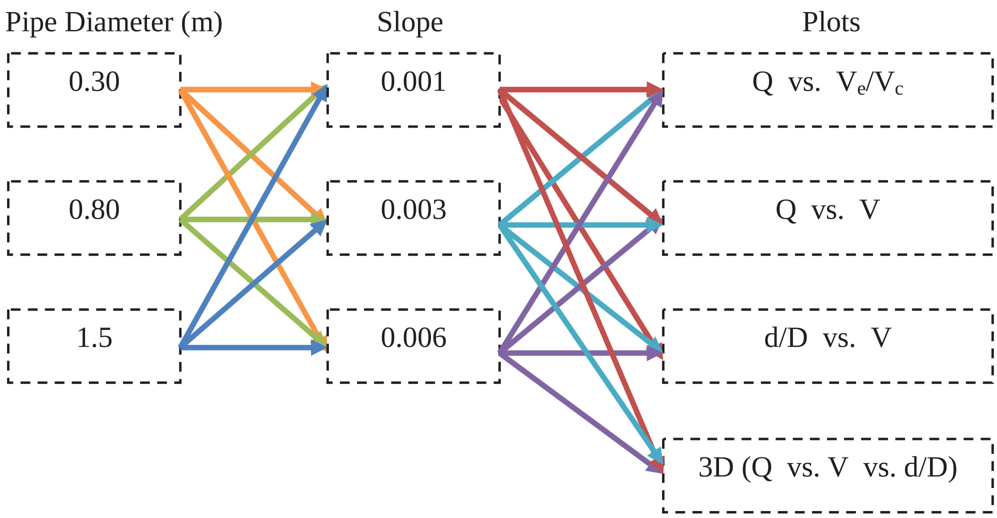


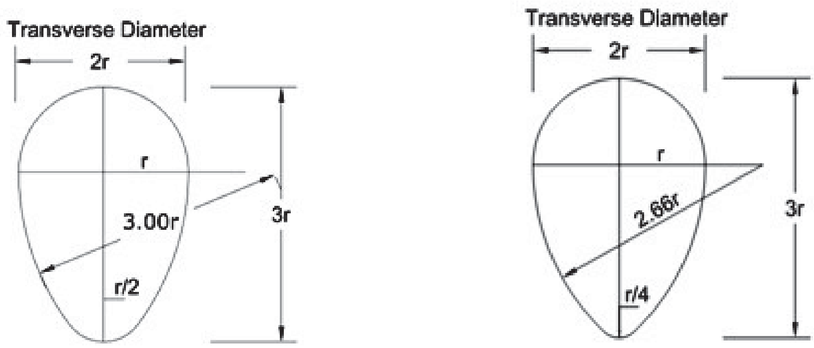
Figure 5.1 Sketch of the plan for the numeric comparison process between circular and non-circular sections.

5.3 Selection of Non-Circular Pipe Shapes

The non-circular sections could be divided into two sub-divisions: the first is the egg-shaped, and the second is the shapes other than egg-shape. Each of the two groups has many alternative sections explained in previous literature. However, based on logic reasons, and also, on the fact that the calculations relevant to the comparison should have some practical limitation to the number of selected sections as well as to the number of attempts for comparison, it appeared essential to select a limited number of sections among each of the two groups.

5.3.1 Selection of the Egg-Shaped Sections

Among the different egg-shaped sections, the form (2:3), where this ratio explains the width over the height of the section, was chosen for being relatively easier for construction and with relatively better hydraulic properties regarding producing higher velocity during low flows. Only two models of this section were selected for a start. The first is of an invert radius of r/2, and the second is of r/4.



A. Egg shape (2:3) - Invert Radius (r/2) **B.** Egg shape (2:3) - Invert Radius (r/4)

Figure 5.2 Egg-shape sections (2:3) with two different invert radiuses.

The invert radius of r/2 and r/4 were selected without going through r/3 simply because the latter would produce results between the other two sections, also, because having a comparison between invert radius of r/2 and r/4 is likely to show more clear difference in the comparison results than when comparing r/2 with r/3, or r/3 with r/4.

The other available egg-shaped sections, as explained in chapter 4 (section 4.4.2.2.B), were eliminated because of the following reasons:

1- Having a cross section that is relatively easy to apply from the excavation and layout point of views. This applies to the oval section in particular, where due to the relatively thin and tall section the excavation would be relatively deep and costly.
2- Having a flow property with relatively little improvement (increase) on the velocity for low flows would not make the section worth consideration due to the large increase in the cost. This applies in particular on the relatively close to round egg-shapes.

Following this stage, it appeared convenient to compare the two selected egg-shaped sections and observe which would be relatively more efficient, and thus, be the only representative to the egg-shaped section.

The comparisons between these two egg-shaped sections were performed with the consideration of all basic principles proposed in section 5.1 except paragraph F. Only then, the difference in behavior made it possible to recommend a particular section over the other. The comparison between the two selected egg-shaped sections is explained in the following section.

The selected Egg shapes 2:3, shown in Figure 5.2, have two different invert radiuses:

A- In Figure 5.2.A, with the consideration that the transverse diameter is the reference value for the rest of the dimensions, the vertical height is equal to one and a half times of that value, the radius of invert is equal to only one fourth of it, and the radius of the sides is one and a half of that value.

B- The other form of Egg-shape, shown in Figure 5.2.B, has a relatively smaller invert in which the vertical height is one and a half times the transverse diameter, the radius of invert is equal to only one eighth of it, and the radius of the sides one and a third times.

The following Figures represent the comparison between the two egg-shaped sections with the consideration of the following changes made on the variables: Pipe cross sectional area, slope, and fullness ratio. Here, it worth repeating that the selection of the different egg-shaped cross-sectional areas used for comparison are based on the cross-sectional areas that matches those of circular pipes with diameters of 0.3m, 0.8m, and 1.5m consecutively. Of course, as stated previously, the same discharge was used in the comparison.

The comparison process was performed on the basis of observing the discharge velocity variation for the same flow discharge in the following different conditions:

I- Three figures for a cross sectional area closest to circular pipe of 0.3m, with slope of 0.001, 0.003, and 0.006. These are Figures 5.3.a, 5.3.b, and 5.3.c.

II- Three figures for a cross sectional area closest to circular pipe of 0.8m, with slope of 0.001, 0.003, and 0.006. These are Figures 5.4.a, 5.4.b, and 5.4.c.

III- Three figures for a cross sectional area closest to circular pipe of 1.5m, with slope of 0.001, 0.003, and 0.006. These are Figures 5.5.a, 5.5.b, and 5.5.c.

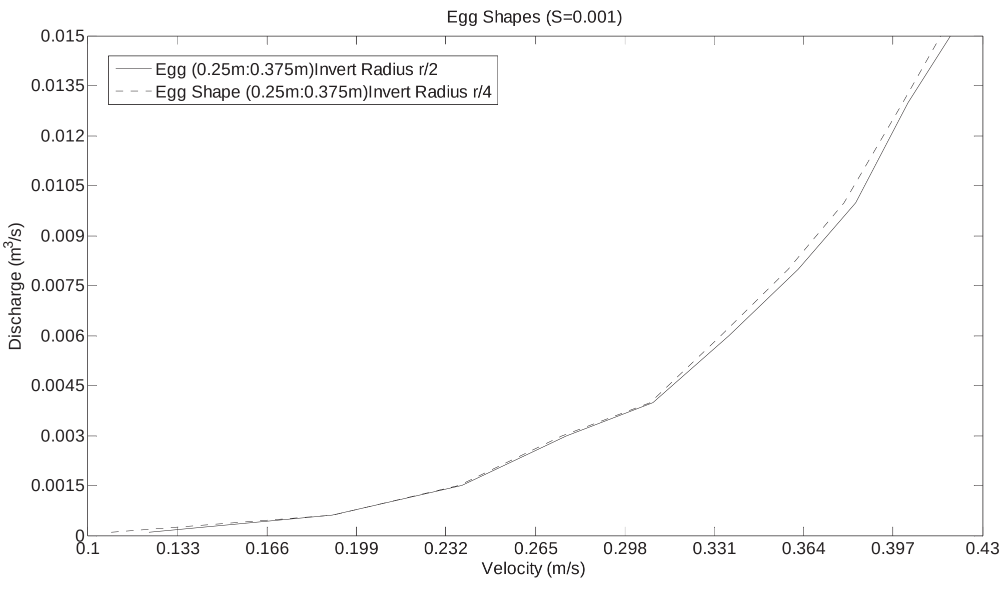


Figure 5.3.a Relation between the discharge and velocity for egg-shaped pipes (2:3) for two different invert radiuses and slope of S=0.001.

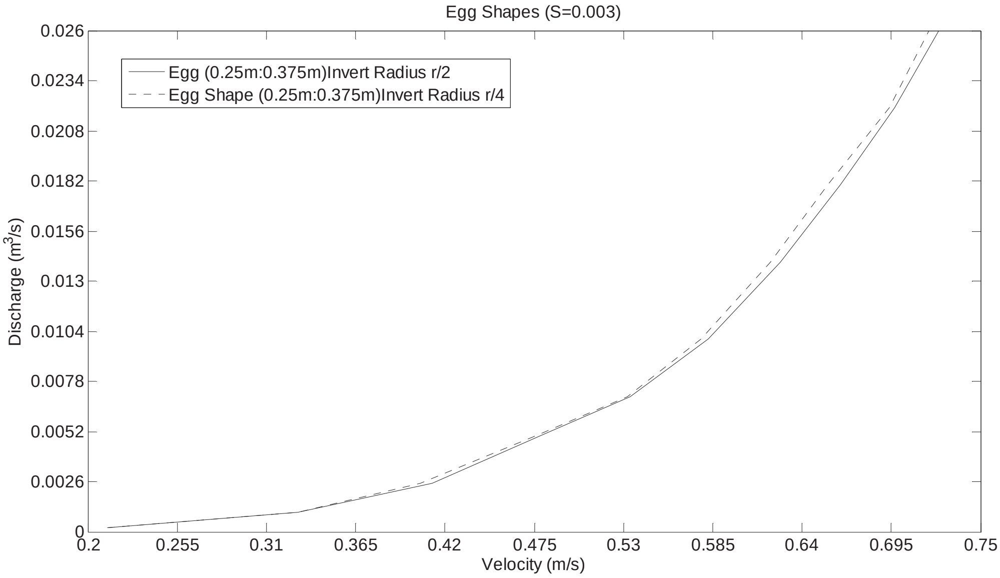


Figure 5.3.b Relation between the discharge and velocity for egg-shaped pipes (2:3) for two different invert radiuses and slope of S=0.003.

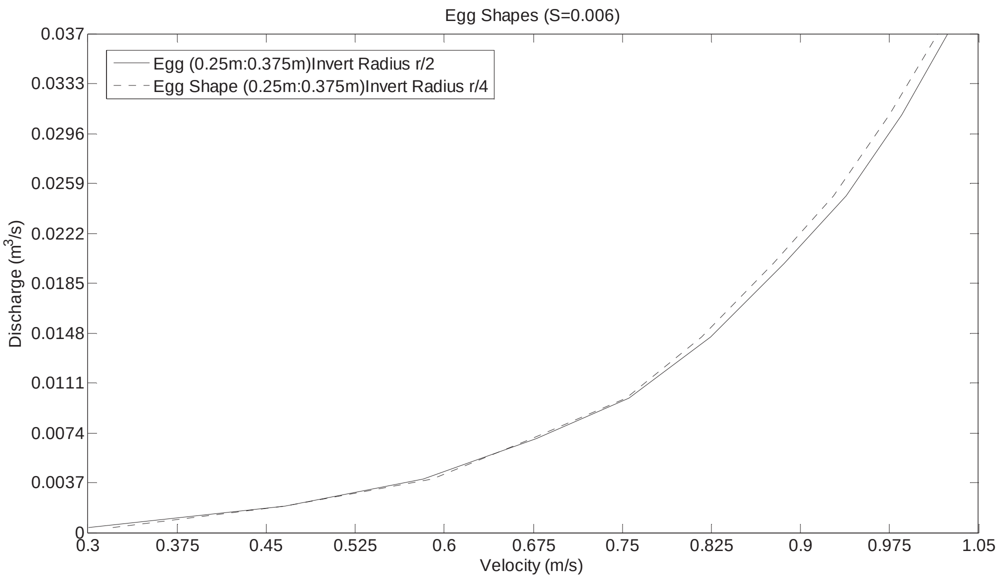


Figure 5.3.c Relation between the discharge and velocity for egg-shaped pipes (2:3) for two different invert radiuses and slope of S=0.006.

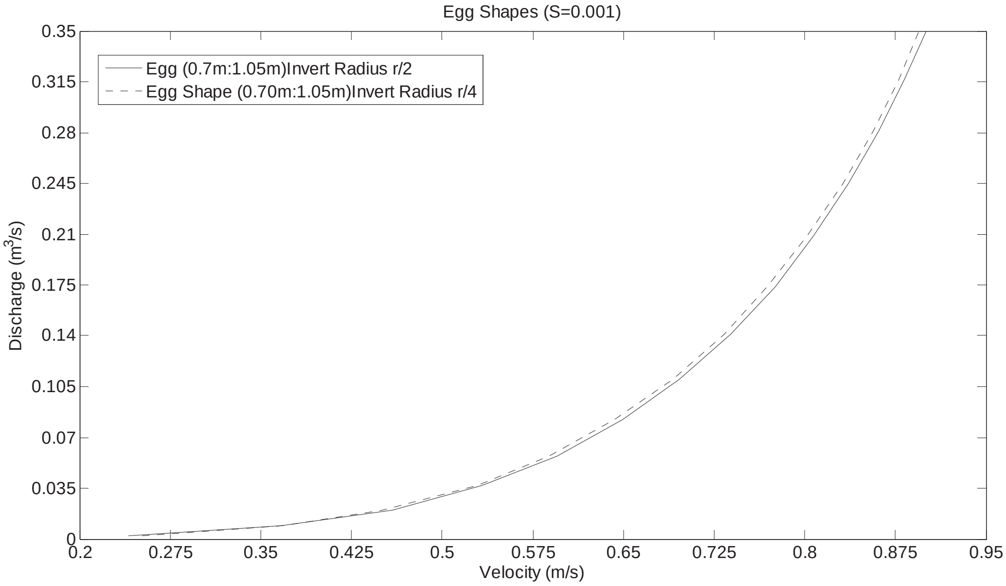


Figure 5.4.a Relation between the discharge and velocity for egg-shaped pipes (2:3) for two different invert radiuses and slope of S=0.001.

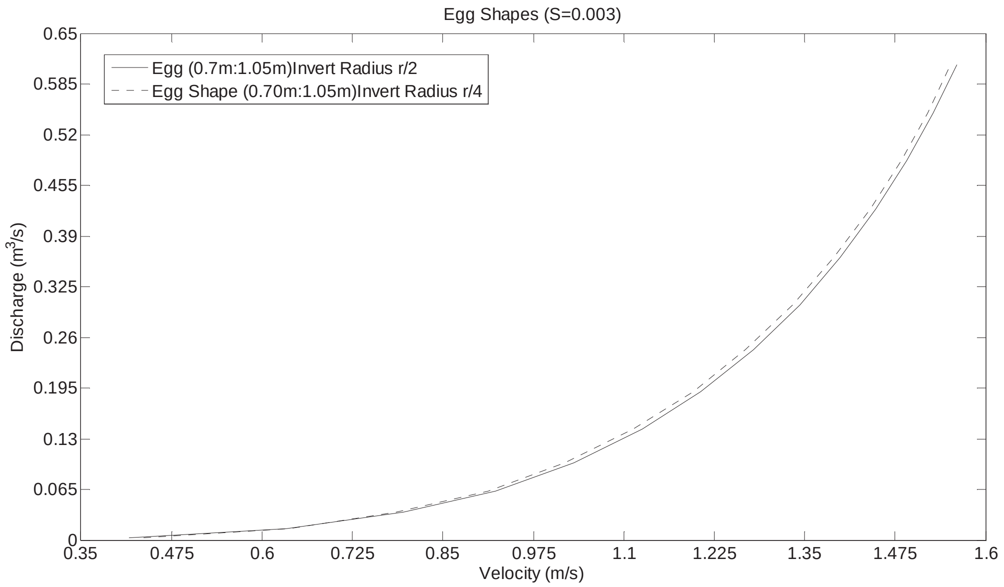


Figure 5.4.b Relation between the discharge and velocity for egg-shaped pipes (2:3) for two different invert radiuses and slope of S=0.003.

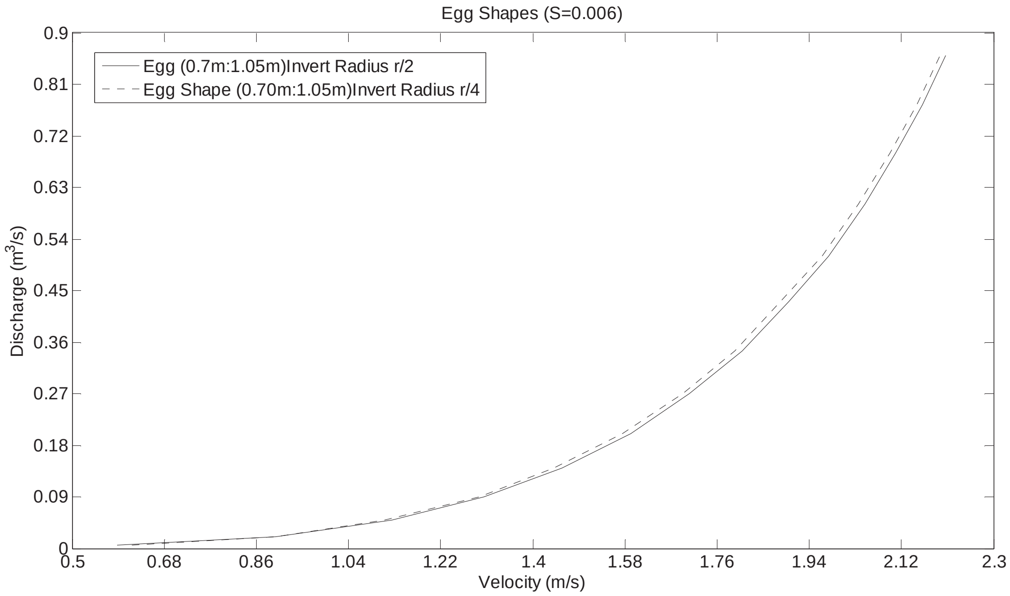


Figure 5.4.c Relation between the discharge and velocity for egg-shaped pipes (2:3) for two different invert radiuses and slope of S=0.006.

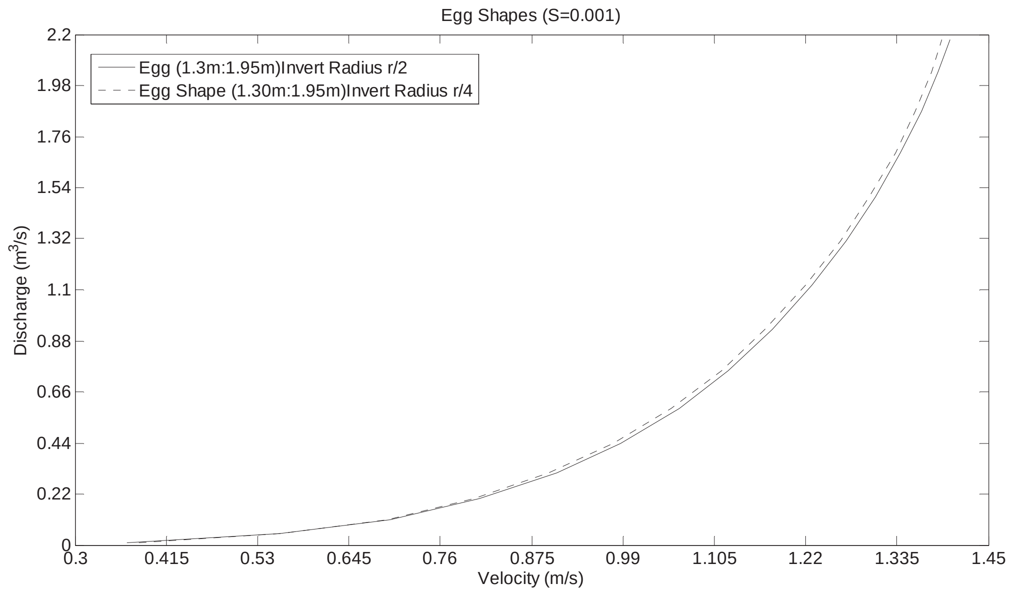


Figure 5.5.a Relation between the discharge and velocity for egg-shaped pipes (2:3) for two different invert radiuses and slope of S=0.001.

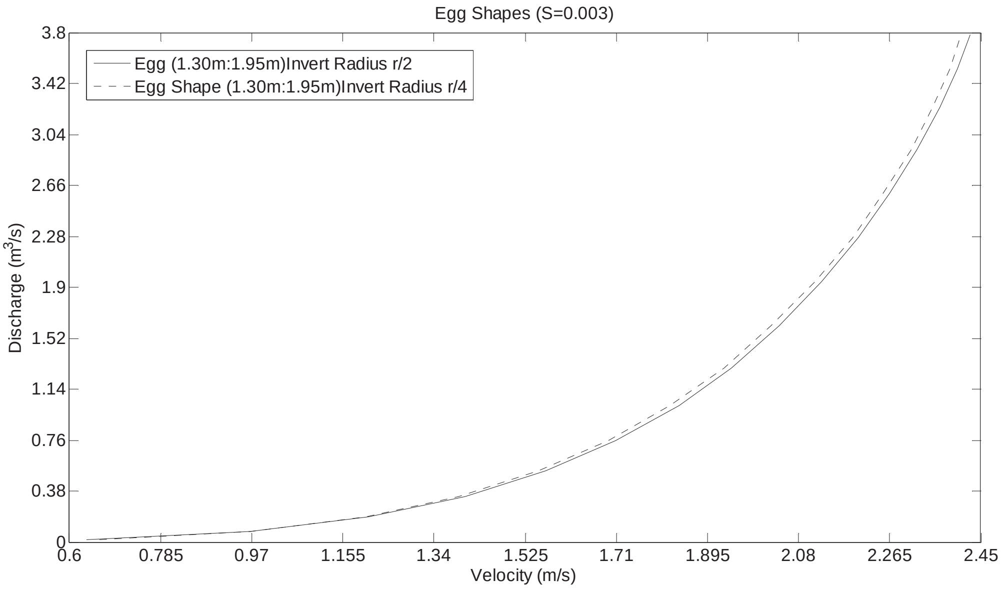


Figure 5.5.b Relation between the discharge and velocity for egg-shaped pipes (2:3) for two different invert radiuses and slope of S=0.003.

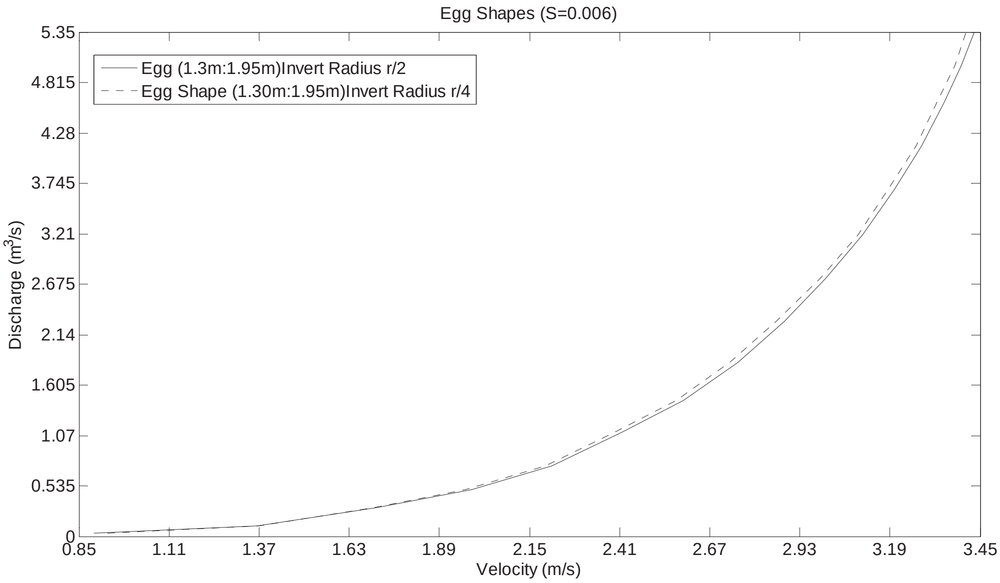


Figure 5.5.c Relation between the discharge and velocity for egg-shaped pipes (2:3) for two different invert radiuses and slope of S=0.006.

During the calculations relevant to both Egg-shapes, it appeared that the Egg-shape of an invert radius (r/2) has slightly higher velocity than Egg-shape of an invert radius (r/4).

Therefore, the Egg-Shaped (2:3) of an invert radius (r/2) is selected to join the other alternative non-circular sections group in order to have this group compared with the circular one.

5.3.2 Selection of the Other Sections

Although there are many sections other than egg-shaped that are proposed in previous literature, there were reasons to select only three among the available alternatives. Those reasons are the following:

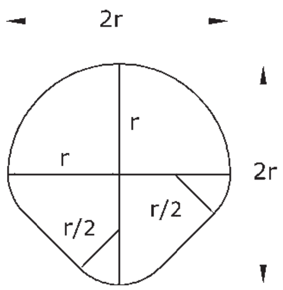
1- The top section appeared to be half a circle, which enables for an easier manufacturing and eventually less cost.
2- The bottom section seems simple and made narrow to increase the velocity for low flows.
3- The total height of the section was acceptable, and thus, does not require much expensive excavation.
4- The selected sections were frequently advertised in companies proposing the section for either new projects, or, for lining the existing projects, that were constructed with circular pipes, in order to convert the section from the inside into the recommended one that increases velocity for low flows.

These cross sections were selected to be the following:

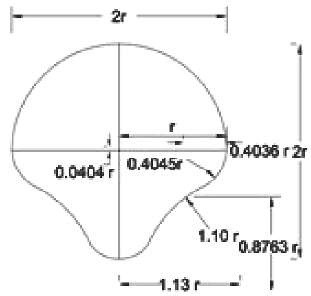
A- Kite shape (2:2).
B- Vase shape (2:2).
C- Mushroom shape (2:2).

In these three sections, the ratio 2:2 indicates the b: h, where b is the width of the section and h is its height; as shown in Figure 5.6.

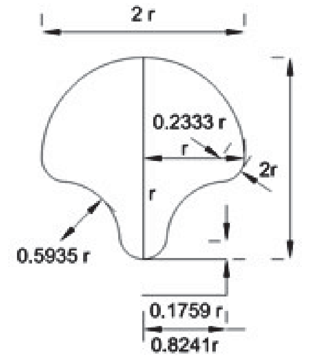
In previous literature, some non-circular shapes do not seem to have any given names, thus, it seemed convenient to give the names ‘Vase’ and ‘Mushroom’ to the shapes shown in Figure 5.6 (B, C) in order to ease the required indication during the comparison process.



A. Kite Shape (2:2)



B. Vase Shape (2:2)



C. Mushroom Shape (2:2)

Figure 5.6 Non-circular pipe cross sections

5.4 Circular and Non-Circular Pipe Calculations (Using Manning Formula)

The required calculations for these plots are performed using MATLAB program. A typical table is shown in Table 5.1.

Table 5.1 Calculations for Circular and Non-Circular Sewer Pipe Cross Sections using Manning Equation (Pipe Grade 0.001- Pipe Diameter 0.30m)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12	Column 13	Column 14	Column 15	Column 16
Sewer Shape	Diameter (m)	Fullness Ratio (d/D)	Discharge (m^3 /s)	Flow Depth (m)	Manning (n)	Slope (S) %	S^0.5	Flow Area (A) m^2	Wetted Perimeter (P) m	Hydraulic Radius (R) m	R^(2/3)	Velocity (V) m	a/A	dt	Ve/Vc
Circular	0.3	0.050	0.0001	0.0150	0.013	0.001	0.03162	0.00130	0.13530	0.0096083	0.0451957	0.1099395	0.01839	0.15	1
Circular	0.3	0.100	0.0006	0.0300	0.013	0.001	0.03162	0.00370	0.19310	0.0191611	0.0716055	0.1741819	0.05233	0.15	1
Circular	0.3	0.150	0.0015	0.0450	0.013	0.001	0.03162	0.00660	0.23870	0.0276498	0.0914382	0.2224254	0.09335	0.15	1
Circular	0.3	0.200	0.0027	0.0600	0.013	0.001	0.03162	0.01010	0.27820	0.0363048	0.1096418	0.266706	0.14286	0.15	1
Circular	0.3	0.250	0.0042	0.0750	0.013	0.001	0.03162	0.01380	0.31420	0.0439211	0.1244845	0.3028112	0.19519	0.15	1
Circular	0.3	0.300	0.0060	0.0900	0.013	0.001	0.03162	0.01780	0.34770	0.0511936	0.1378723	0.3353772	0.25177	0.15	1
Circular	0.3	0.350	0.0080	0.1050	0.013	0.001	0.03162	0.02200	0.37980	0.0579252	0.149708	0.364168	0.31117	0.15	1
Circular	0.3	0.400	0.0103	0.1200	0.013	0.001	0.03162	0.02640	0.41090	0.0642492	0.1604151	0.3902131	0.37341	0.15	1
Circular	0.3	0.450	0.0128	0.1350	0.013	0.001	0.03162	0.03090	0.44120	0.0700363	0.1699086	0.4133062	0.43706	0.15	1
Circular	0.3	0.500	0.0153	0.1500	0.013	0.001	0.03162	0.03530	0.47120	0.0749151	0.1777104	0.4322844	0.499	0.15	1
Egg Shape	0.25:0.375 (b:h)	0.0520	0.0001	0.0195	0.013	0.001	0.03162	0.00110	0.09730	0.0113052	0.0503717	0.1225302	0.01532	0.16875	1.11452426
Egg Shape	0.25:0.375 (b:h)	0.1047	0.0006	0.0393	0.013	0.001	0.03162	0.00330	0.15100	0.0218543	0.0781672	0.1901434	0.04596	0.16875	1.091637287
Egg Shape	0.25:0.375 (b:h)	0.1594	0.0015	0.0598	0.013	0.001	0.03162	0.00610	0.19950	0.0305764	0.0977818	0.2378563	0.08496	0.16875	1.069375621
Egg Shape	0.25:0.375 (b:h)	0.2191	0.0027	0.0822	0.013	0.001	0.03162	0.00960	0.25050	0.0383234	0.1136691	0.2765024	0.1337	0.16875	1.036731203
Egg Shape	0.25:0.375 (b:h)	0.2753	0.0041	0.1033	0.013	0.001	0.03162	0.01340	0.29700	0.0451178	0.1267357	0.3082872	0.18663	0.16875	1.018084039
Egg Shape	0.25:0.375 (b:h)	0.3317	0.0059	0.1244	0.013	0.001	0.03162	0.01760	0.34240	0.0514019	0.138246	0.3362864	0.24513	0.16875	1.002710894
Egg Shape	0.25:0.375 (b:h)	0.3882	0.0080	0.1456	0.013	0.001	0.03162	0.02220	0.38690	0.0573792	0.1487657	0.3618757	0.30919	0.16875	0.993705476
Egg Shape	0.25:0.375 (b:h)	0.4440	0.0103	0.1665	0.013	0.001	0.03162	0.02690	0.43010	0.0625436	0.1575634	0.3832762	0.37465	0.16875	0.982222853
Egg Shape	0.25:0.375 (b:h)	0.4996	0.0128	0.1873	0.013	0.001	0.03162	0.03180	0.47260	0.0672873	0.165433	0.4024194	0.4429	0.16875	0.973659154
Egg Shape	0.25:0.375 (b:h)	0.5500	0.0152	0.2063	0.013	0.001	0.03162	0.03640	0.51080	0.0712608	0.1718833	0.4181098	0.5070	0.16875	0.967209858
Kite Shape	0.35:0.35 (b:h)	0.04857	0.0001	0.0170	0.013	0.001	0.03162	0.00120	0.11090	0.0108206	0.0489215	0.1190026	0.01342	0.1918	1.082437334
Kite Shape	0.35:0.35 (b:h)	0.10000	0.0006	0.0350	0.013	0.001	0.03162	0.00320	0.15850	0.0201893	0.0741448	0.1803587	0.03579	0.1918	1.035462021
Kite Shape	0.35:0.35 (b:h)	0.15080	0.0015	0.0528	0.013	0.001	0.03162	0.00630	0.21420	0.0294118	0.0952827	0.2317772	0.07047	0.1918	1.042044769
Kite Shape	0.35:0.35 (b:h)	0.21010	0.0029	0.0735	0.013	0.001	0.03162	0.01040	0.27300	0.0380952	0.1132176	0.2754041	0.11633	0.1918	1.032613098
Kite Shape	0.35:0.35 (b:h)	0.24670	0.0040	0.0863	0.013	0.001	0.03162	0.01340	0.30920	0.0433376	0.1233797	0.3001236	0.14989	0.1918	0.991124637
Kite Shape	0.35:0.35 (b:h)	0.29190	0.0057	0.1022	0.013	0.001	0.03162	0.01750	0.35390	0.049449	0.1347219	0.327714	0.19575	0.1918	0.97715048
Kite Shape	0.35:0.35 (b:h)	0.34130	0.0081	0.1195	0.013	0.001	0.03162	0.02260	0.40200	0.0562189	0.1467534	0.3569808	0.2528	0.1918	0.980264128
Kite Shape	0.35:0.35 (b:h)	0.38120	0.0103	0.1334	0.013	0.001	0.03162	0.02710	0.43570	0.0621988	0.1569837	0.3818661	0.30313	0.1918	0.978609206
Kite Shape	0.35:0.35 (b:h)	0.41760	0.0126	0.1462	0.013	0.001	0.03162	0.03130	0.46360	0.0675151	0.1658061	0.403327	0.35011	0.1918	0.975854996
Kite Shape	0.35:0.35 (b:h)	0.45210	0.0150	0.1582	0.013	0.001	0.03162	0.03550	0.48860	0.0726566	0.1741205	0.4235518	0.39709	0.1918	0.979798968

Table 5.1 (Continued)

Vase Shape	0.35:0.35 (b:h)	0.0514	0.0001	0.0180	0.0130	0.001	0.03162	0.00110	0.0962	0.0114345	0.050755	0.1234625	0.01313	0.171	1.123004177
Vase Shape	0.35:0.35 (b:h)	0.1143	0.0006	0.0400	0.0130	0.001	0.03162	0.00330	0.1471	0.0224337	0.0795428	0.1934895	0.03938	0.171	1.110847762
Vase Shape	0.35:0.35 (b:h)	0.1800	0.0015	0.0630	0.0130	0.001	0.03162	0.00620	0.2022	0.0306627	0.0979656	0.2383035	0.07399	0.171	1.071386117
Vase Shape	0.35:0.35 (b:h)	0.2500	0.0028	0.0875	0.0130	0.001	0.03162	0.01010	0.2687	0.0375884	0.1122111	0.2729559	0.12053	0.171	1.023433526
Vase Shape	0.35:0.35 (b:h)	0.3028	0.0042	0.1060	0.0130	0.001	0.03162	0.01400	0.3288	0.0425791	0.1219357	0.2966111	0.16706	0.171	0.979525051
Vase Shape	0.35:0.35 (b:h)	0.3571	0.0061	0.1250	0.0130	0.001	0.03162	0.01910	0.4032	0.047371	0.1309208	0.3184676	0.22792	0.171	0.949580282
Vase Shape	0.35:0.35 (b:h)	0.3971	0.0080	0.1390	0.0130	0.001	0.03162	0.02340	0.4419	0.0529532	0.1410137	0.3430188	0.27924	0.171	0.941924493
Vase Shape	0.35:0.35 (b:h)	0.4371	0.0104	0.1530	0.0130	0.001	0.03162	0.02810	0.4740	0.0592827	0.1520379	0.3698355	0.33532	0.171	0.947778374
Vase Shape	0.35:0.35 (b:h)	0.4743	0.0128	0.1660	0.0130	0.001	0.03162	0.03260	0.5012	0.0650439	0.1617351	0.3934241	0.38902	0.171	0.951894991
Vase Shape	0.35:0.35 (b:h)	0.5114	0.0154	0.1790	0.0130	0.001	0.03162	0.03710	0.5275	0.0703318	0.1703862	0.4144679	0.44272	0.171	0.958785258
Mushroom Shape	0.40:0.40 (b:h)	0.0450	0.0001	0.018	0.013	0.001	0.03162	0.0011	0.0962	0.0114345	0.050755	0.1234625	0.01103	0.195	1.123004177
Mushroom Shape	0.40:0.40 (b:h)	0.1000	0.0006	0.0400	0.0130	0.001	0.03162	0.00330	0.1471	0.0224337	0.0795428	0.1934895	0.0331	0.195	1.110847762
Mushroom Shape	0.40:0.40 (b:h)	0.1900	0.0015	0.0760	0.0130	0.001	0.03162	0.00630	0.2069	0.0304495	0.0975109	0.2371975	0.06319	0.195	1.066413649
Mushroom Shape	0.40:0.40 (b:h)	0.2750	0.0028	0.1100	0.0130	0.001	0.03162	0.01050	0.2855	0.0367776	0.1105916	0.2690164	0.10532	0.195	1.008662695
Mushroom Shape	0.40:0.40 (b:h)	0.3340	0.0042	0.1336	0.0130	0.001	0.03162	0.01450	0.3557	0.0407647	0.1184466	0.288124	0.14544	0.195	0.951497141
Mushroom Shape	0.40:0.40 (b:h)	0.4000	0.0062	0.1600	0.0130	0.001	0.03162	0.02140	0.5240	0.0408397	0.1185919	0.2884773	0.21464	0.195	0.860157769
Mushroom Shape	0.40:0.40 (b:h)	0.4300	0.0081	0.1720	0.0130	0.001	0.03162	0.02590	0.5601	0.0462417	0.1288317	0.3133859	0.25978	0.195	0.860553048
Mushroom Shape	0.40:0.40 (b:h)	0.4604	0.0104	0.1842	0.0130	0.001	0.03162	0.03060	0.5878	0.0520585	0.1394209	0.3391443	0.30692	0.195	0.869125928
Mushroom Shape	0.40:0.40 (b:h)	0.4875	0.0126	0.1950	0.0130	0.001	0.03162	0.03490	0.6101	0.0572037	0.1484623	0.3611378	0.35005	0.195	0.873777688
Mushroom Shape	0.40:0.40 (b:h)	0.5125	0.0148	0.2050	0.0130	0.001	0.03162	0.03890	0.6301	0.0617362	0.1562045	0.3799707	0.39017	0.195	0.878982979

Each table consists of a group of five different sewer pipes. These are as follows:

1- Circular cross section
2- Egg shaped pipe (2:3).
3- Kite shape (2:2).
4- Vase shape (2:2).
5- Mushroom shape (2:2).

All groups of pipes were considered to have the same Manning coefficient n of 0.013. The contents of the columns in a typical table are as follows:

Column 1: Name of the sewer pipe;

Column 2: Diameter and dimension of sewer pipe. Each dimension ratio in non circular pipes indicates the ratio of width b to the height h in m;

Column 3: Fullness ratio;

Column 4: Flow depth within the pipe in m;

Column 5: Manning Coefficient n for the pipe;

Column 6: Pipe slope S;

Column 7: Square root of the pipe slope;

Column 8: Flow area a in the pipe in contrast with fullness ratio in (m^2);

Column 9: Wetted perimeter p for each flow area in m;

Column 10: Hydraulic radius of the pipe R which is equal to A/P in m;

Column 11: Hydraulic radius to the power 2/3;

Column 12: Velocity v for each flow area which is equal to ($R^{2/3} * S^{0.5}/n$) in m/s;

Column 13: Discharge q in the pipe which is equal to v*a in m^3/s;

Column 14: Flow area ratio a/A;

Column 15: Empty height above flow surface in m;

Column 16: Velocity ratio V_e/V_c between circular and non-circular pipes.

A typical table of the explained calculations is presented in Table 5.1.

5.4.1 Circular Pipe (0.3m) in Diameter vs. Three Slopes (0.001, 0.003, and 0.006)

In this section, there are three groups; these three groups aim to compare selected non-circular sections with a circular one of 0.3m diameter for three selected slopes of 0.001, 0.003, and 0.006 respectively.

Each of these three groups contains four figures of the following properties:

1- The relation between flow velocity ratio V_e/V_c (non-circular/circular) and discharge q. In this group of Figures/plots, the circular pipe will show its velocity ratio V_e/V_c as a horizontal line. In fact, this is intended in order to ease the relative comparison and observe the behavior for the rest of the sections.
2- The relation between flow velocity v and discharge q.
3- The relation between fullness ratio d/D and velocity v.
4- 3D relation among the velocity v, discharge q, and fullness ratio d/D.

A. Figures 5.7 (a - d) Non-Circular Sections in Comparison with a Circular Pipe of 0.3m in Diameter for Slope S = 0.001

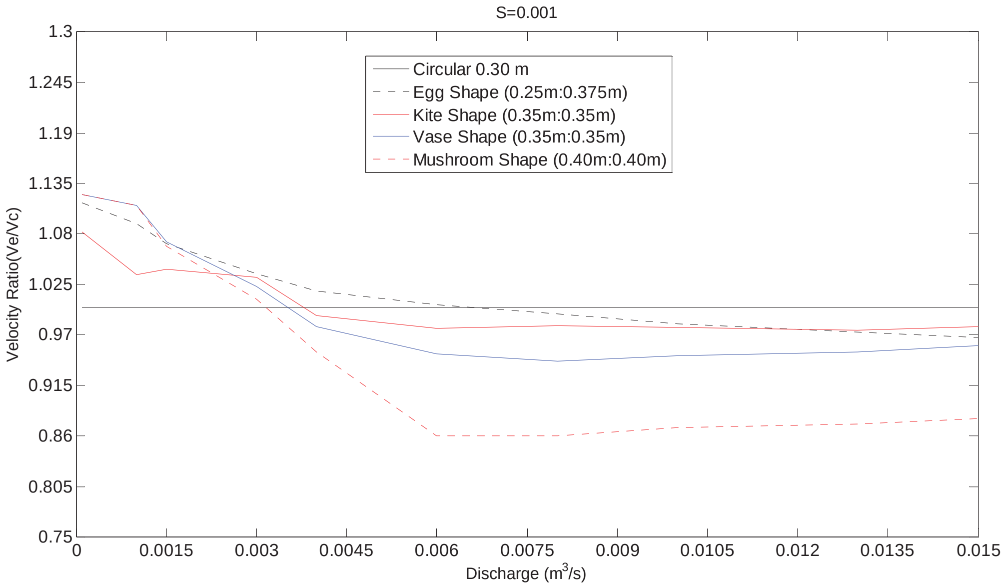


Figure 5.7.a The relation between flow velocity ratio Ve/Vc (non-circular/circular) and discharge for slope S = 0.001.

In Figure 5.7a, it can be clearly seen that for the initial/relatively low discharge 0.0001m^3/s, the overall trend for non-circular curves shows fluctuation with slight increase in velocity ratio V_e/V_c in comparison to the velocity ratio of the circular section.

Starting with Egg shaped section, the curve rose up to 1.11 in 0.0001m^3/s then gradually declined to 1 in 0.0066 m^3/s, and continued to decrease but gently to 0.967 in 0.015 m^3/s.

Followed by Vase shape, the curve which rose to 1.123 by 0.0001m^3/s and dropped to 1 in 0.0035 m^3/s, then, continued to decrease to 0.935 in 0.008 m^3/s with a little increase to 0.95 in 0.015 m^3/s.

The last two curves (Kite and Mushroom shapes) increased to 1.08 and 1.123 respectively. The Kite shape curve dropped to 1 in 0.0038 m^3/s, and continued to decrease but gently to 0.98 in 0.015 m^3/s, while the Mushroom shape decreased to 1 in 0.0032 m^3/s, and dropped steeply to 0.85 m^3/s in 0.006 then showed gentle increase to 0.88 in 0.015 m^3/s.

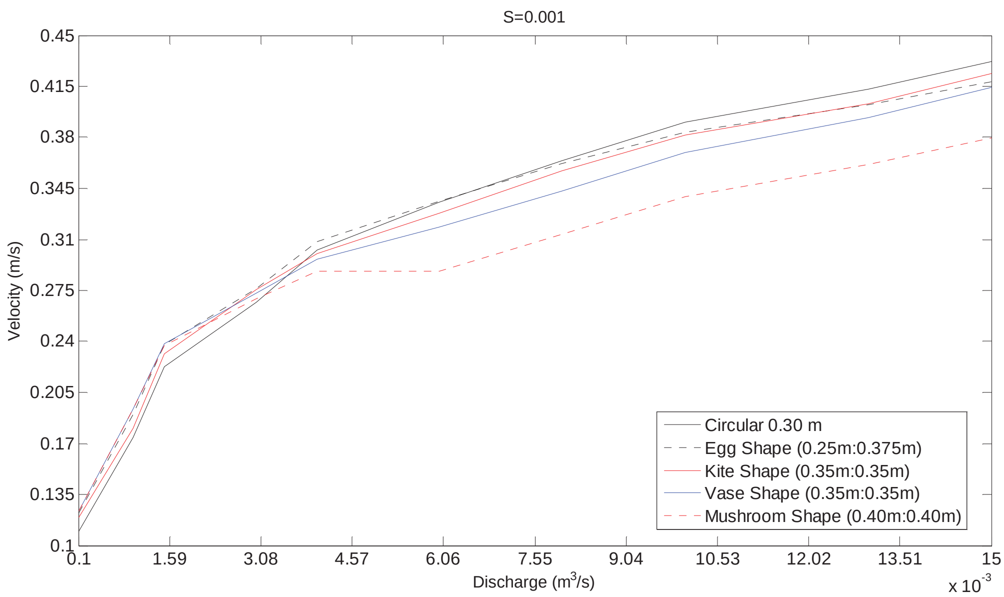


Figure 5.7.b Relation between flow velocity and discharge in circular and non-circular pipes for slope S = 0.001.

Figure 5.7.b indicates the variation in the velocity versus discharge for the circular and non-circular sections, all flow with slope of S = 0.001, and a range of discharge between 0.0001 and 0.015m^3/s.

In non-circular pipes, for low flow discharges with fullness ratio less than around 25%, the overall trend of non-circular sections show slightly higher velocity in comparison with the circular one. After that, they show gradual decrease and fall below the circular curve with intersection points in different ranges.

The fact behind different curvature tendencies is that, each form of circular and non circular sections has different variation in the ratio of A/P. Thus, with the increase in discharge, the ratio A/P would increase in each non-circular section in a different way.

After the fullness ratio exceeds around 25%, the circular section shows a better performance regarding the velocity when compared with the other non-circular sections.

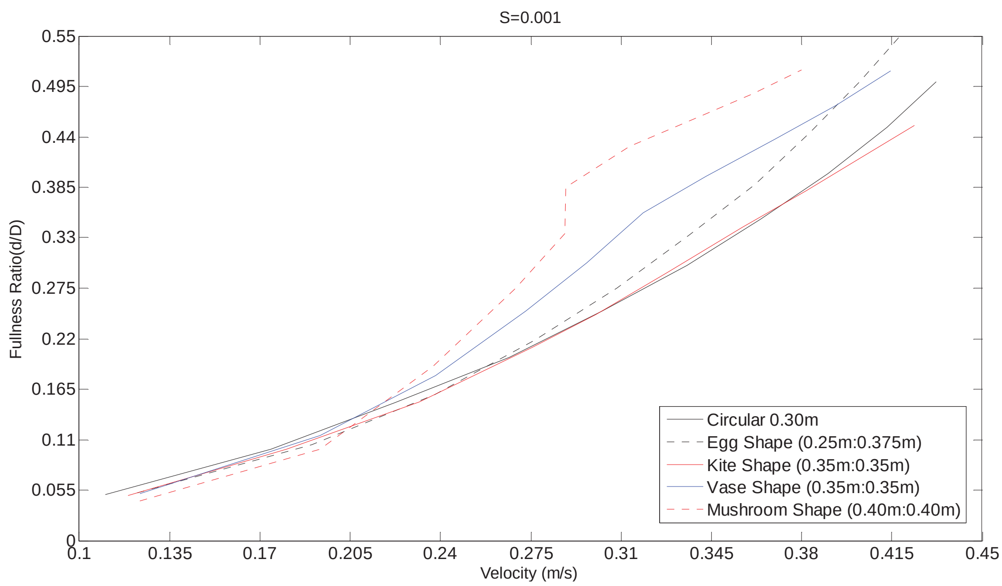


Figure 5.7.c The relation between fullness ratio and velocity in circular and non-circular pipes for slope S = 0.001.

In Figure 5.7.c, the relatively wide range of variation among the curves is related mainly to the difference in the depth of flow resulting from having different sections

(particularly the lower half of each non-circular section) when applying the same value of discharge for all sections alike.

The curve relevant to the Mushroom section shows sudden vertical increase where the fullness ratio is around 35%. Obviously, this is due to the sudden widening of the section at that height.

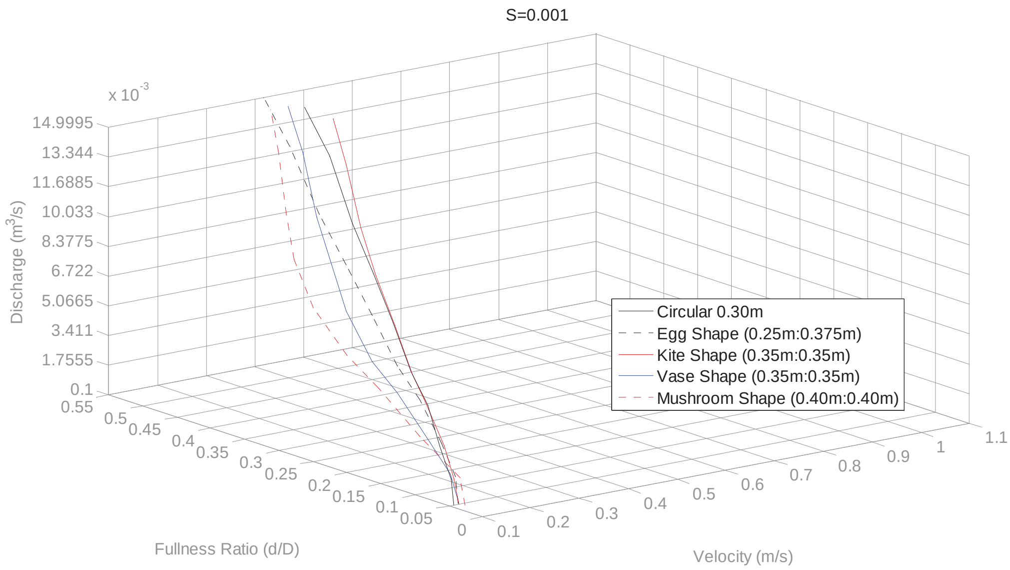


Figure 5.7.d 3D relation among flow discharge, fullness ratio, and velocity in circular and non-circular pipes for slope S = 0.001.

A. Figures 5.8 (a - d) Non-Circular Sections in Comparison with a Circular Pipe of 0.3m in Diameter for Slope S = 0.003

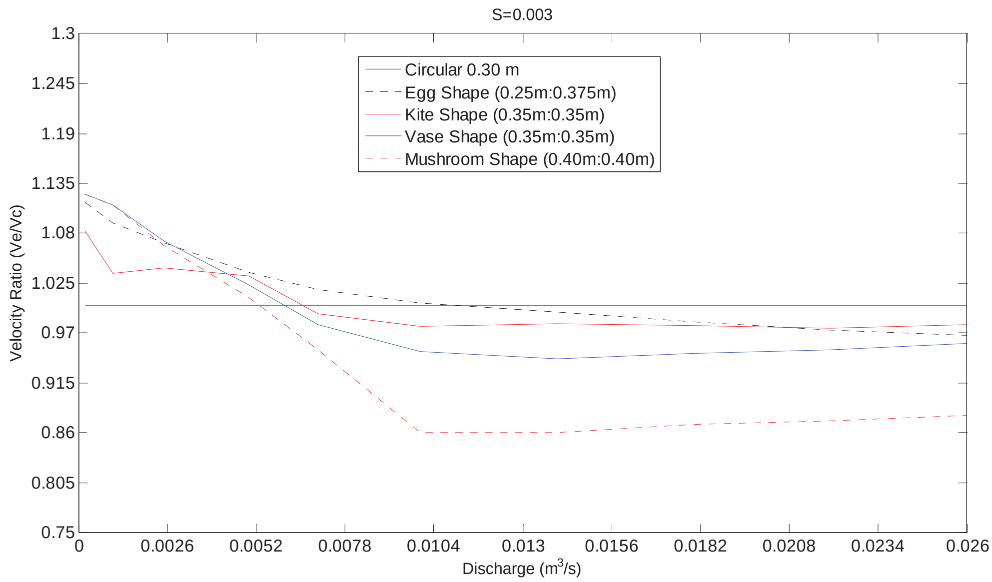


Figure 5.8.a The relation between flow velocity ratio V_e/V_c (non-circular/circular) and discharge for slope S = 0.003.

In Figure 5.8.a, the comparison results have the same velocity ratio V_e/V_c in comparison with the previous case S = 0.001(explained in Figure 5.7.a). The only difference is the range of discharge which is between 0.0002 and 0.026 m^3/s.

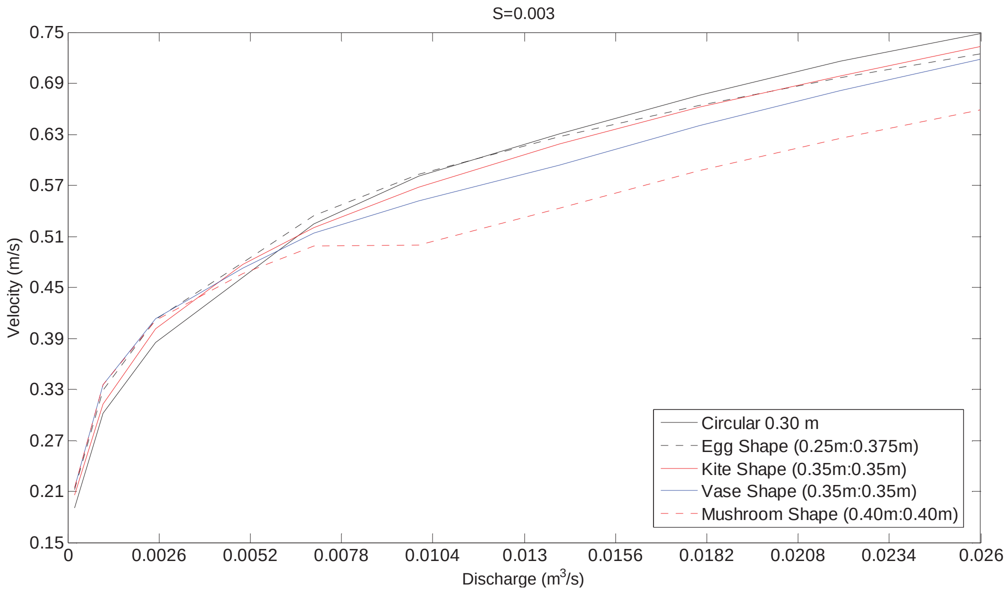


Figure 5.8.b Relation between flow velocity and discharge in circular and non-circular pipes for slope S = 0.003.

Figure 5.8.b indicates the variation in the velocity versus discharge for the circular and non-circular sections, all flow with slope of S = 0.003, and a range of discharge between 0.0002 and 0.026m^3/s. The comparison result relatively shows the same curve tendencies in comparison with previous case S = 0.001(explained in Figure 5.7.b). The only difference is the range of the discharge along with the velocity.

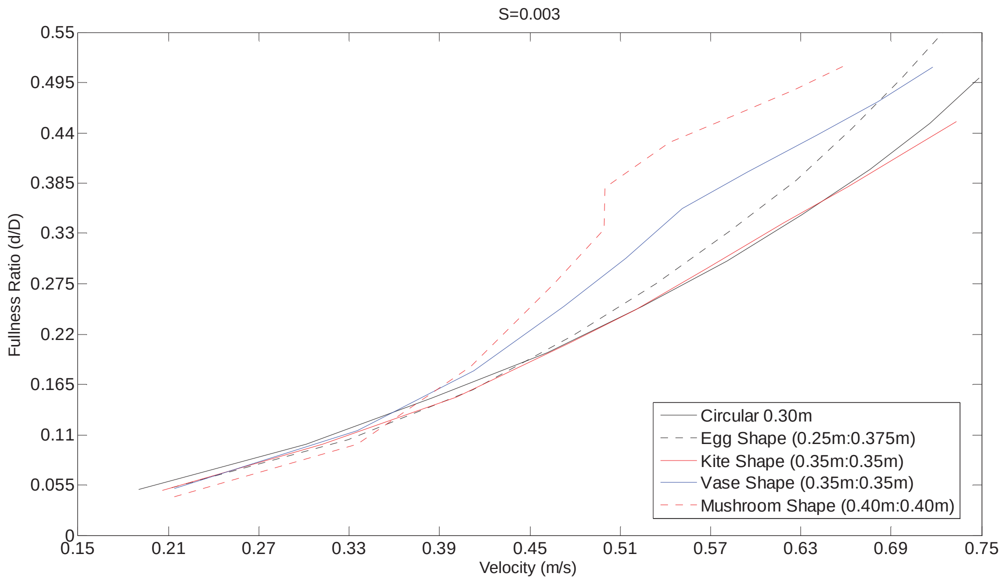


Figure 5.8.c The relation between fullness ratio and velocity in circular and non-circular pipes for slope S = 0.003.

In Figure 5.8.c, the comparison result shows relatively the same curve tendencies in comparison with previous case S = 0.001(explained in Figure 5.7.c). The only difference is the range of the velocity.

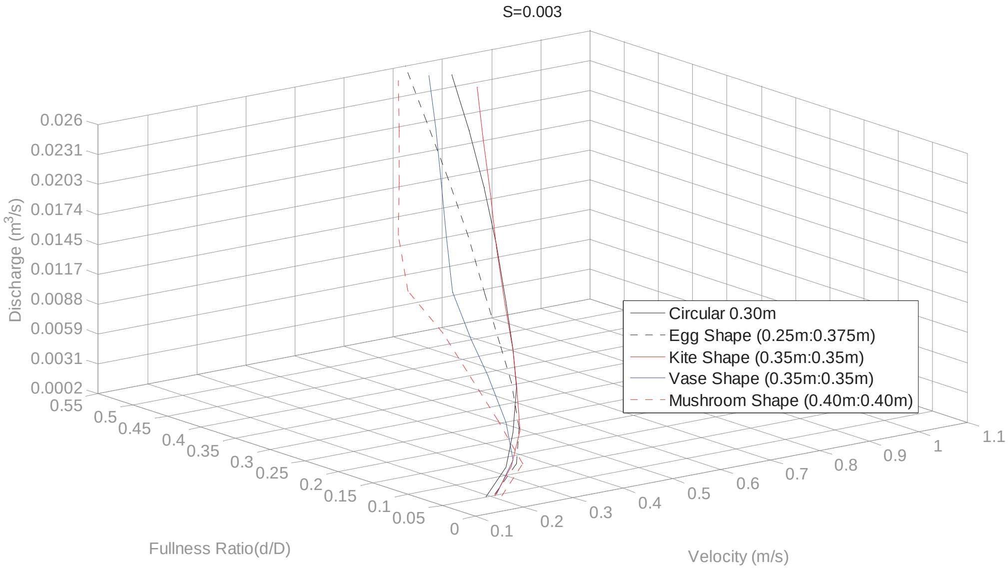


Figure 5.8.d 3D relation among flow discharge, fullness ratio, and velocity in circular and non-circular pipes for slope S = 0.003.

B. Figures 5.9 (a - d) Non-Circular Sections in Comparison with a Circular Pipe of 0.3m in Diameter for Slope S = 0.006

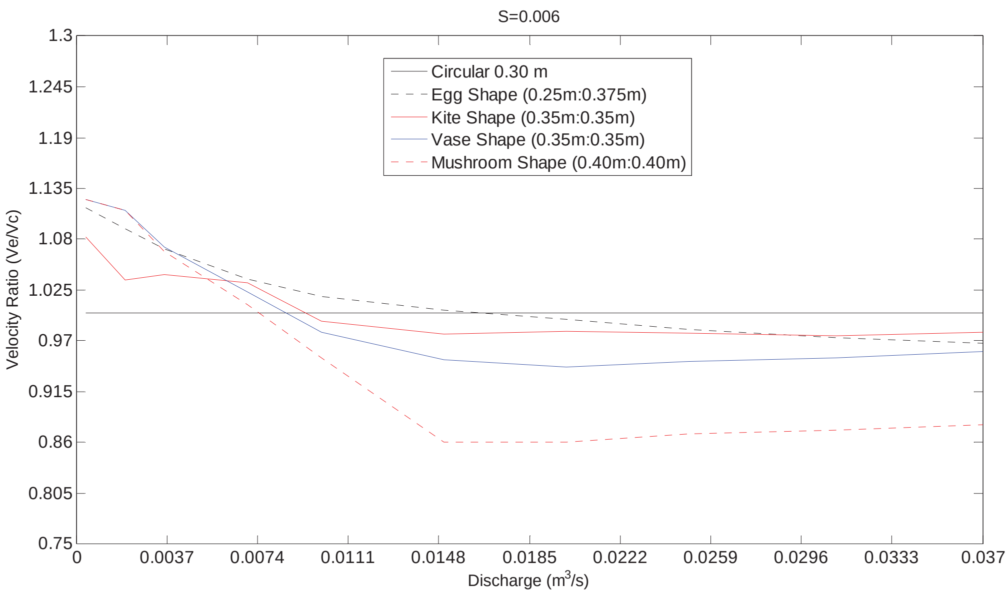


Figure 5.9.a The relation between flow velocity ratio Ve/Vc (non-circular/circular) and discharge for slope S = 0.006.

In Figure 5.9.a, the comparison results have the same velocity ratio V_e/V_c in comparison with the previous case S = 0.001(explained in Figure 5.7.a). The only difference is the range of discharge which is between 0.0004 and 0.037 m^3/s.

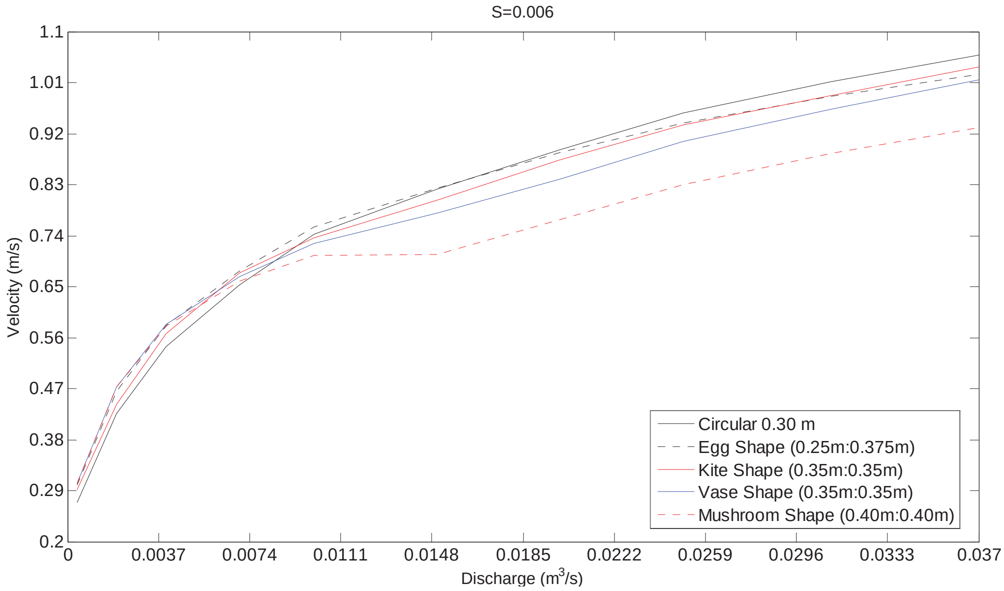


Figure 5.9.b Relation between flow velocity and discharge in circular and non circular pipes for slope S = 0.006.

Figure 5.9.b indicates the variation in the velocity versus discharge for the circular and non-circular sections, all flow with slope of S = 0.006, and a range of discharge between 0.0004 and 0.037m^3/s. The comparison result relatively shows relatively the same curve tendencies in comparison with the previous case S = 0.001(explained in Figure 5.7.b). The only difference is the range of the discharge along with the velocity.

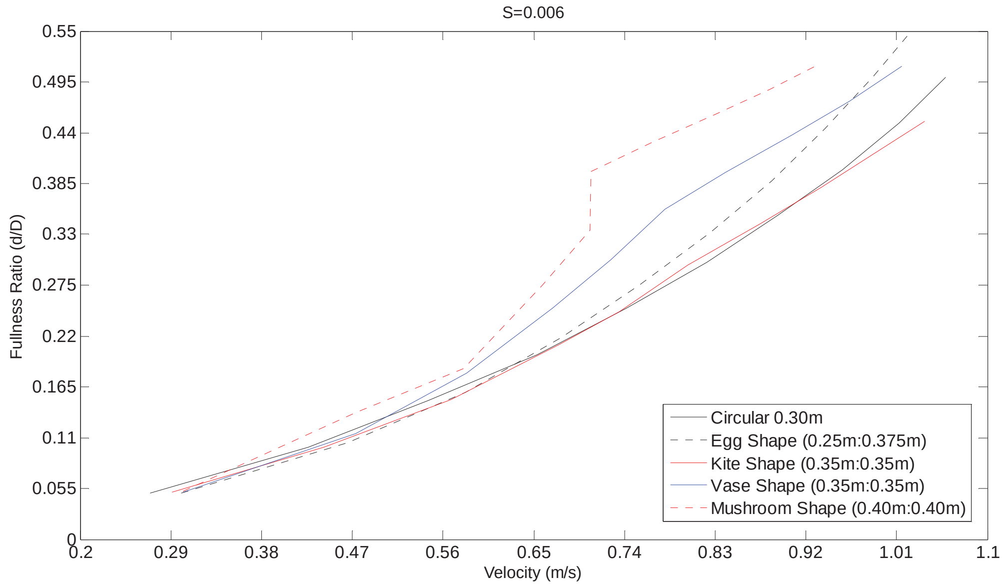


Figure 5.9.c The relation between fullness ratio and velocity in circular and non-circular pipes for slope S = 0.006.

In Figure 5.9.c, the comparison result shows relatively the same curve tendencies in comparison with the previous case S = 0.001(explained in Figure 5.7.c), the only difference is the range of the velocity.

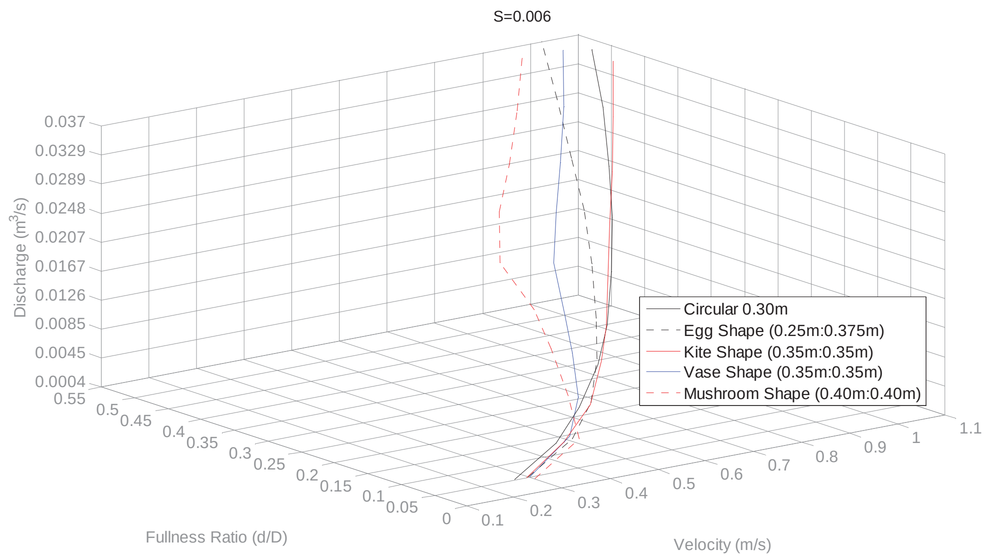


Figure 5.9.d 3D relation among flow discharge, fullness ratio, and velocity in circular and non-circular pipes for slope S = 0.006.

5.4.2 Circular Pipe (0.8m) in Diameter vs. Three Slopes (0.001, 0.003, and 0.006)

In this section, there are three groups; these three groups aim to compare selected non-circular sections with a circular one of 0.8m diameter for three selected slopes of 0.001, 0.003, and 0.006 respectively.

Each of these three groups contains four figures of the following properties:

1- The relation between flow velocity ratio V_e/V_c (non-circular/circular) and discharge q. In this group of Figures/plots, the circular pipe will show its velocity ratio V_e/V_c as a horizontal line. In fact, this is intended in order to ease the relative comparison and observe the behavior for the rest of the sections.
2- The relation between flow velocity v and discharge q.
3- The relation between fullness ratio d/D and velocity v.
4- 3D relation among the velocity v, discharge q, and fullness ratio d/D.

A. Figures 5.10 (a - d) Non-Circular Sections in Comparison with a Circular Pipe of 0.8m in Diameter for Slope S = 0.001

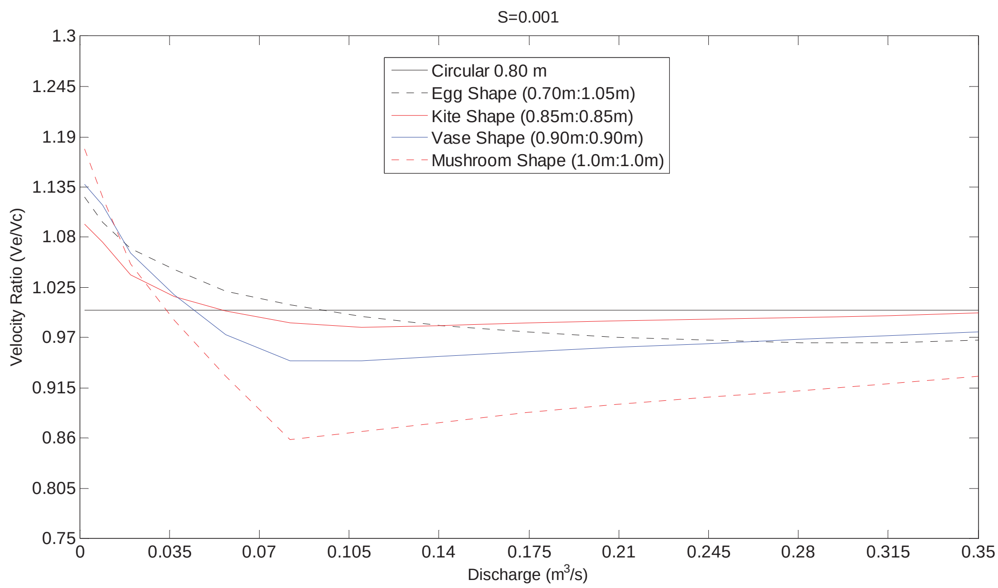


Figure 5.10.a The relation between flow velocity ratio Ve/Vc (non-circular/circular) and discharge for slope S = 0.001.

In Figure 5.10.a, it can be clearly seen that for the initial/relatively low discharge 0.002m^3/s, the overall trend for non-circular curves shows fluctuation with slight increase in velocity ratio V_e/V_c in comparison to the velocity ratio of the circular section.

Starting with Mushroom shaped section, the curve rose up to 1.176 in 0.002m^3/s then gradually declined to 1 in 0.033 m^3/s, and continued to decrease but gently to 0.858 in 0.082m^3/s with a little increase to 0.927 in 0.35 m^3/s.

Followed by Egg shape, the curve which rose to 1.123 in 0.002m^3/s and dropped to 1 in 0.1 m^3/s, then, continued to decrease to 0.931 in 0.35 m^3/s.

The last two curves (Vase and Kite shapes) increased to 1.138 and 1.09 respectively. The Vase shape curve dropped to 1 in 0.0449 m^3/s, and continued to decrease but gently to 0.955 in 0.085 m^3/s, while the Kite shape decreased to 1 in 0.0562 m^3/s, and decreased to 0.975 m^3/s in 0.13 m^3/s with a little increase to 0.99 in 0.35 m^3/s.

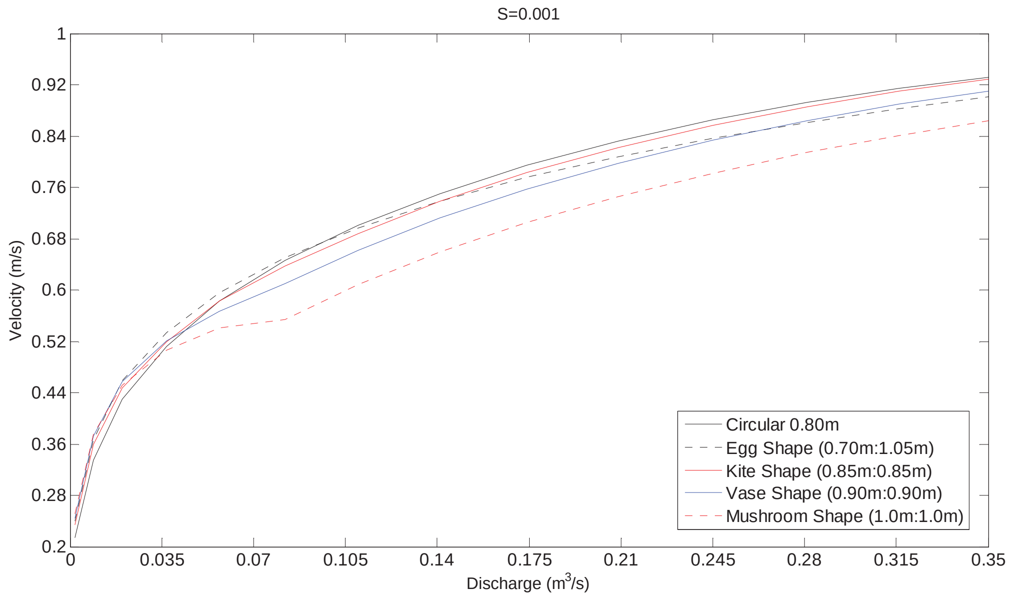


Figure 5.10.b Relation between flow velocity and discharge in circular and non-circular pipes for slope S = 0.001.

Figure 5.10.b indicates the variation in the velocity versus discharge for the circular and non-circular sections, all flow with slope of S = 0.001, and a range of discharge between 0.002 and 0.35m^3/s.

In non-circular pipes, for low flow discharges with fullness ratio less than around 25%, the overall trend of non-circular sections show slightly higher velocity in comparison with the circular one. After that, they show gradual decrease and fall below the circular curve with intersection points in different ranges.

The fact behind different curvature tendencies is that, each form of circular and non circular sections has different variation in the ratio of A/P. Thus, with the increase in discharge, the ratio A/P would increase in each non-circular section in a different way.

After the fullness ration exceeds around 25%, the circular section shows a better performance regarding the velocity when compared with the other non-circular sections.

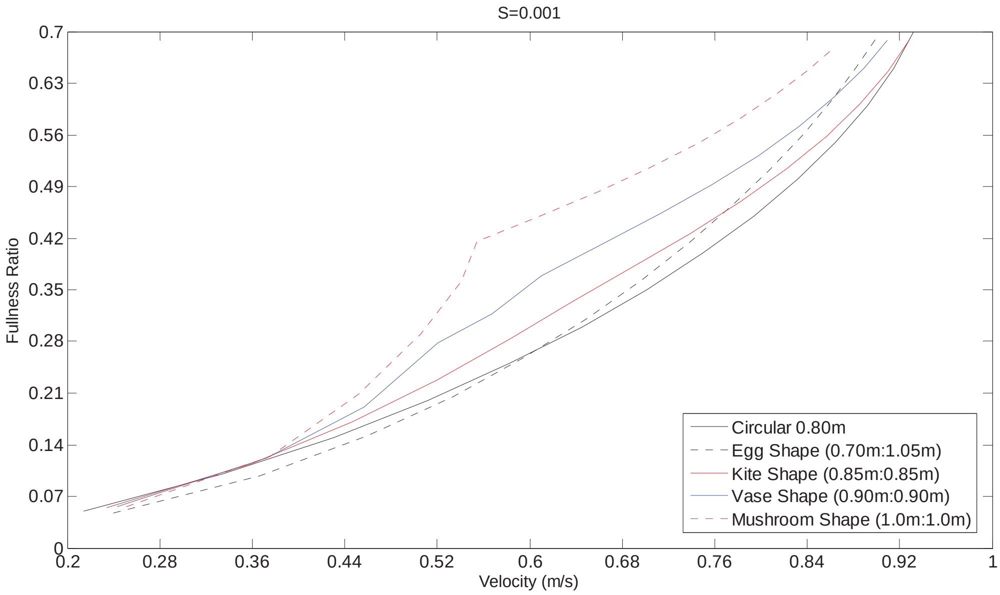


Figure 5.10.c The relation between fullness ratio and velocity in circular and non-circular pipes for slope S = 0.001.

In Figure 5.10.c, the relatively wide range of variation among the curves is related mainly to the difference in the depth of flow resulting from having different sections

(particularly the lower half of each non-circular section) when applying the same value of discharge for all sections alike.

The curve relevant to the Mushroom section shows vertical increase where the fullness ratio is around 35%. Obviously, this is due to the sudden widening of the section at that height.

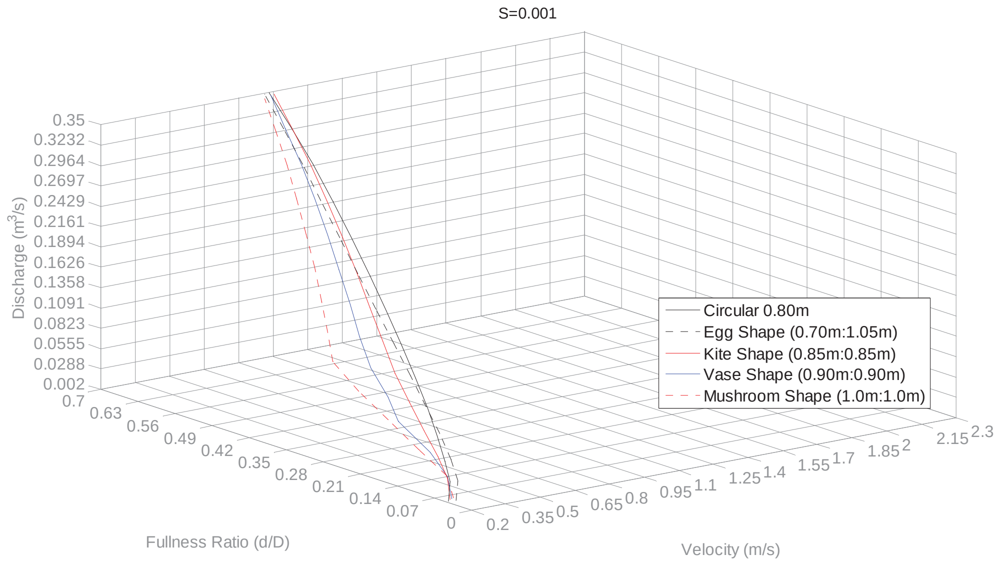


Figure 5.10.d 3D relation among flow discharge, fullness ratio, and velocity in circular and non-circular pipes for slope S = 0.001.

B. Figures 5.11 (a - d) Non-Circular Sections in Comparison with a Circular Pipe of 0.8m in Diameter for Slope S = 0.003

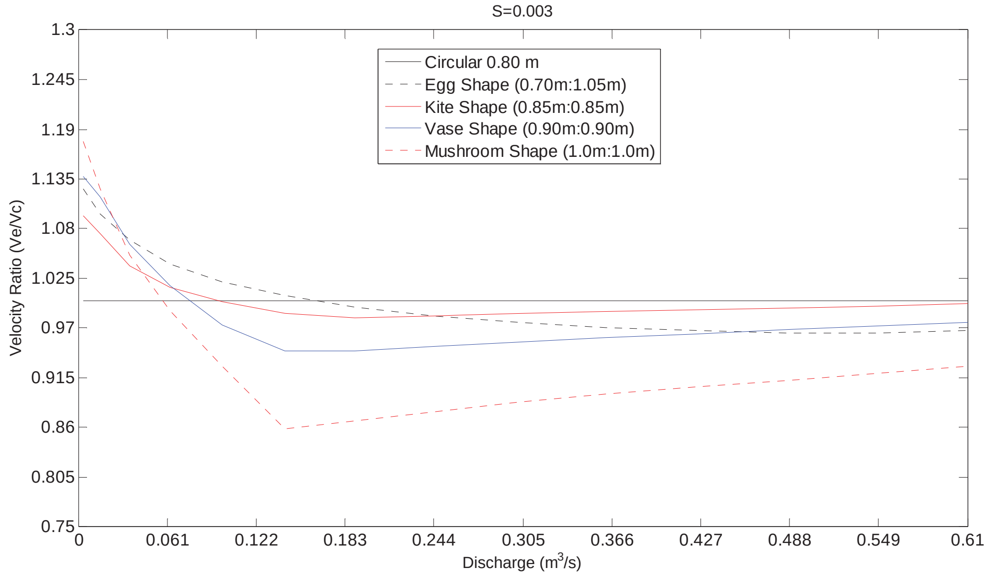


Figure 5.11.a The relation between flow velocity ratio V_e/V_c (non-circular/circular) and discharge for slope S = 0.003.

In Figure 5.11.a, the comparison results have the same velocity ratio V_e/V_c in comparison with the previous case S = 0.001(explained in Figure 5.10.a). The only difference is the range of discharge which is between 0.0035 and 0.61 m^3/s.

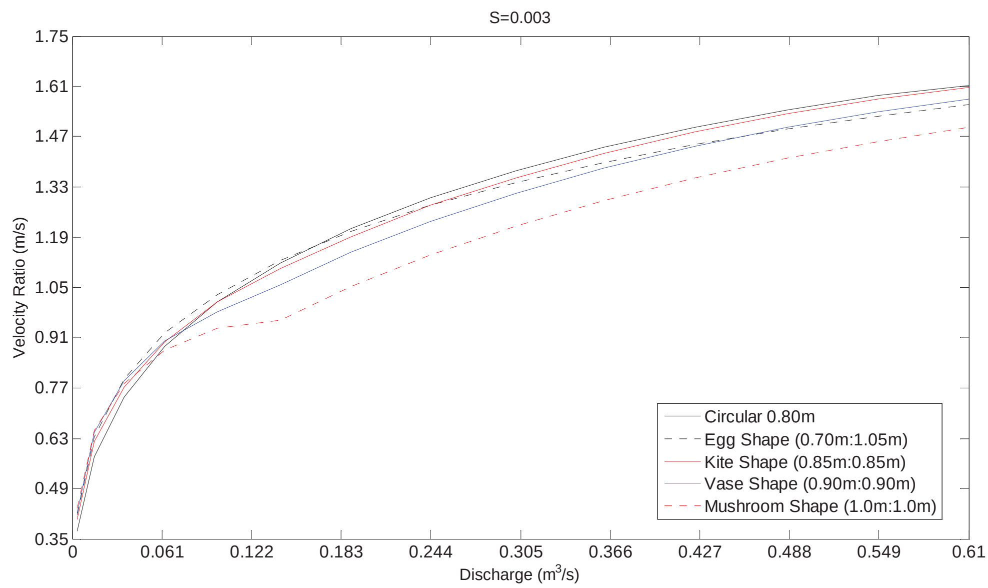


Figure 5.11.b Relation between flow velocity and discharge in circular and non circular pipes for slope S = 0.003.

Figure 5.11.b indicates the variation in the velocity versus discharge for the circular and non-circular sections, all flow with slope of S = 0.003, and a range of discharge between 0.0035 and 0.61 m^3/s. The comparison relatively shows similar result of curve tendencies in comparison with the previous case S = 0.001(explained in Figure 5.10.b), the only difference is the range of the discharge along with the velocity.

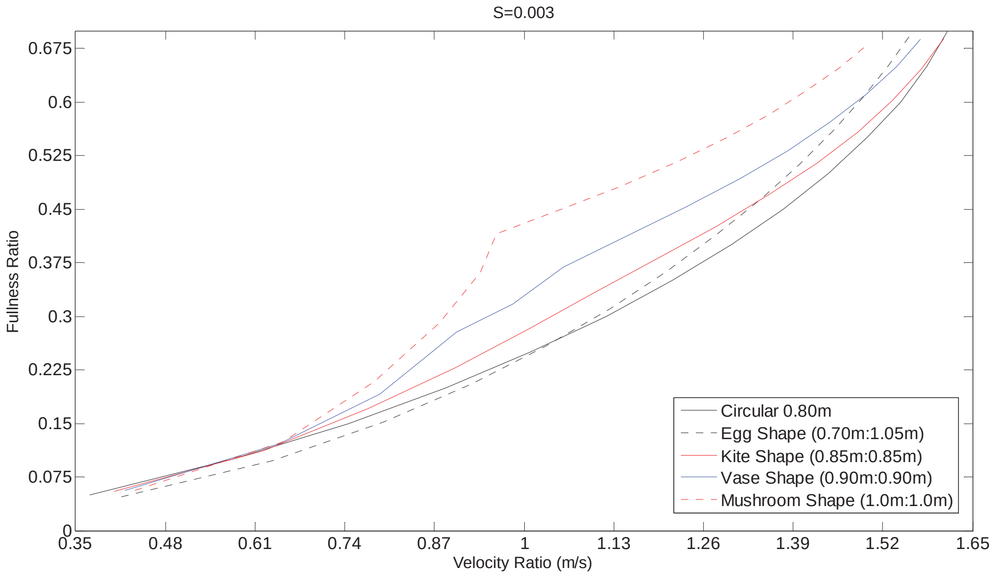


Figure 5.11.c The relation between fullness ratio and velocity in circular and non-circular pipes for slope S = 0.003.

In Figure 5.11.c, the comparison result shows relatively the same curve tendencies in comparison with the previous case S = 0.001(explained in Figure 5.10.c), the only difference is the range of the velocity.

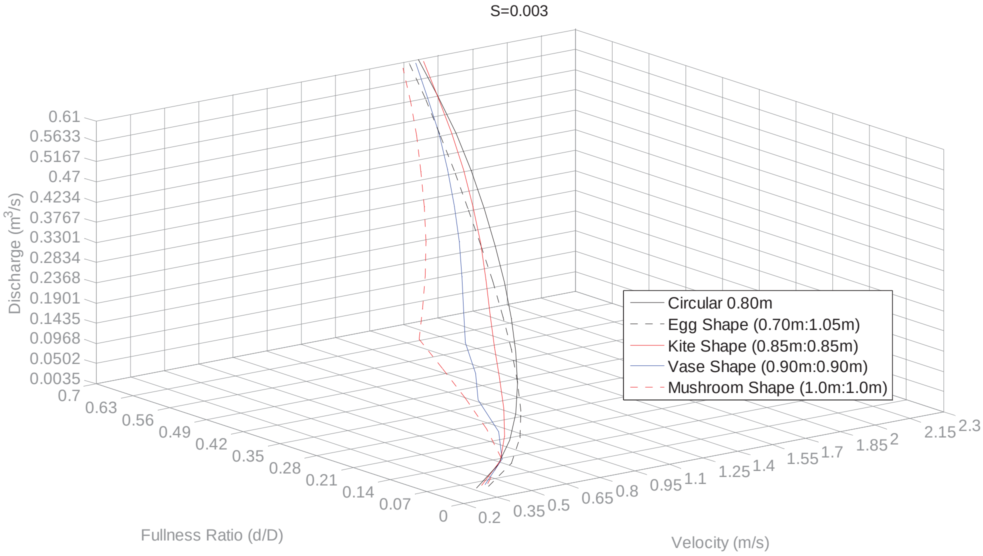


Figure 5.11.d 3D relation among flow discharge, fullness ratio, and velocity in circular and non-circular pipes for slope S = 0.003.

Figures 5.12 (a - d) Non-Circular Sections in Comparison with a Circular Pipe of 0.8m in Diameter for Slope S = 0.006

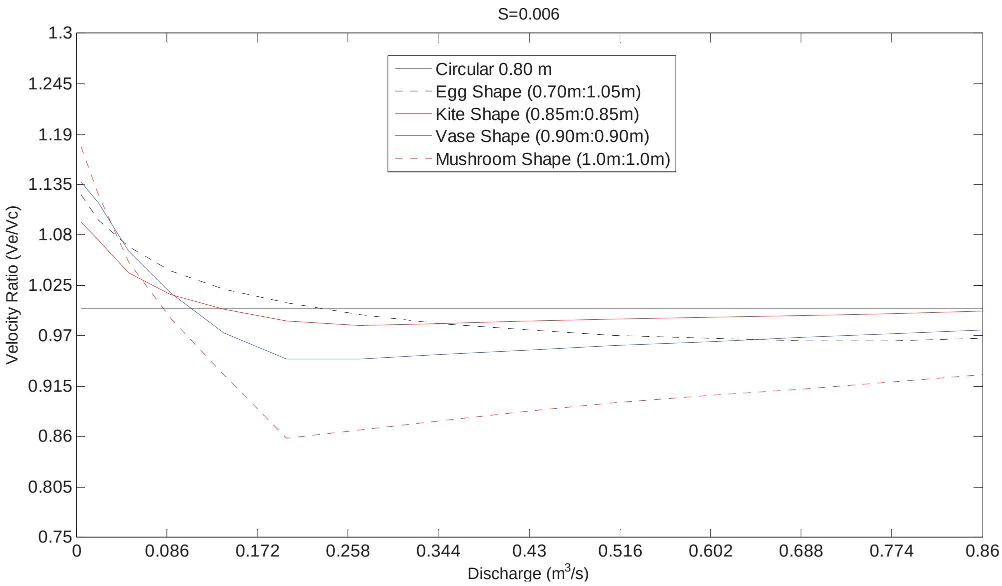


Figure 5.12.a The relation between flow velocity ratio Ve/Vc (non-circular/circular) and discharge for slope S = 0.006.

In Figure 5.12.a, the comparison results have the same velocity ratio V_e/V_c in comparison with the previous case S = 0.001(explained in Figure 5.10.a). The only difference is the range of discharge which is between 0.005 and 0.86 m^3/s.

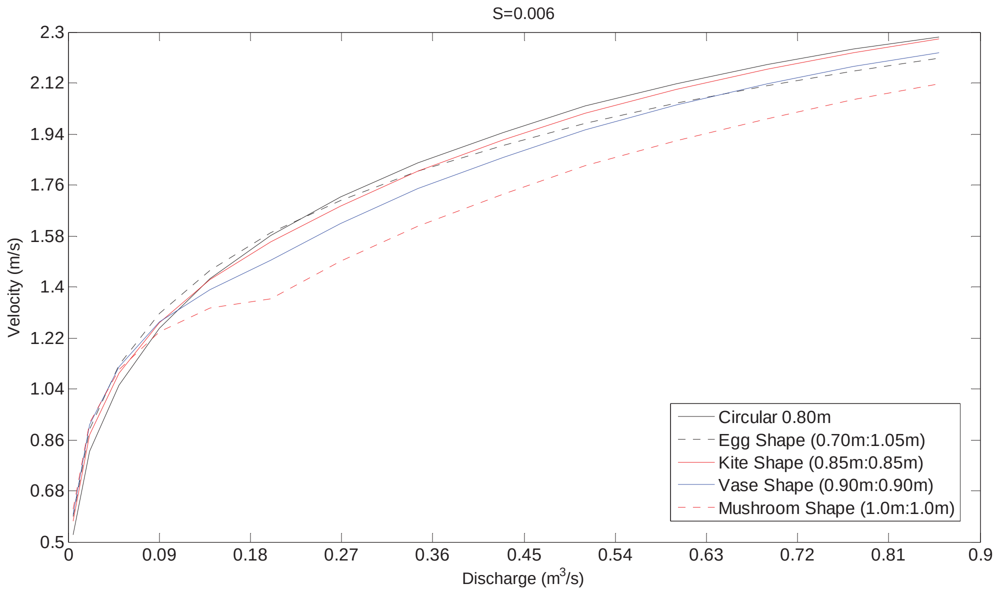


Figure 5.12.b Relation between flow velocity and discharge in circular and non-circular pipes for slope S = 0.006.

Figure 5.12.b indicates the variation in the velocity versus discharge for the circular and non-circular sections, all flow with slope of S = 0.006, and a range of discharge between 0.005 and 0.86 m^3/s. The comparison relatively shows similar result of curve tendencies in comparison with the previous case S = 0.001(explained in Figure 5.10.b). The only difference is the range of the discharge along with the velocity.

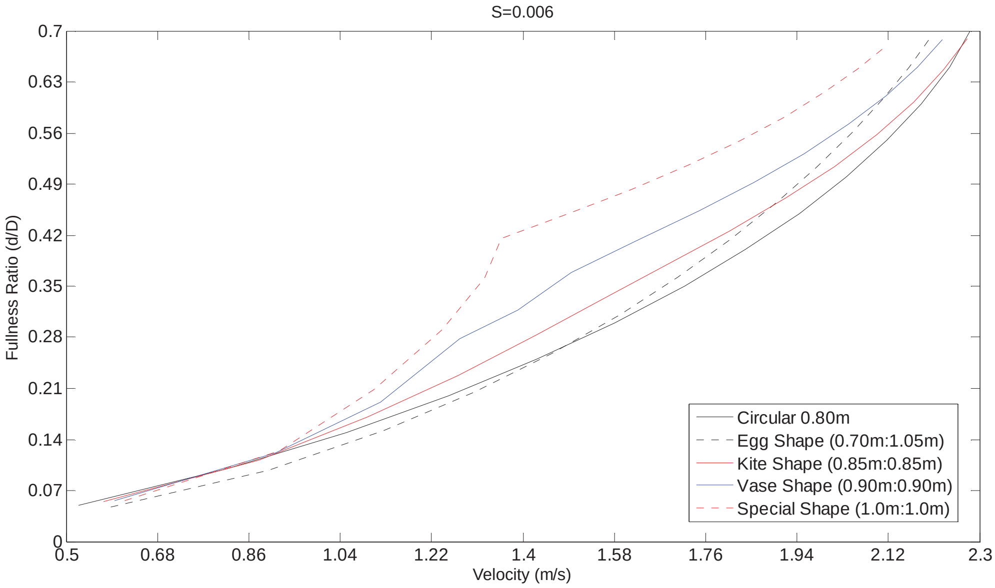


Figure 5.12.c The relation between fullness ratio and velocity in circular and non-circular pipes for slope S = 0.006.

In Figure 5.12.c, the comparison result relatively shows the same curve tendencies in comparison with the previous case S = 0.001(explained in Figure 5.10.c), the only difference is the range of the velocity.

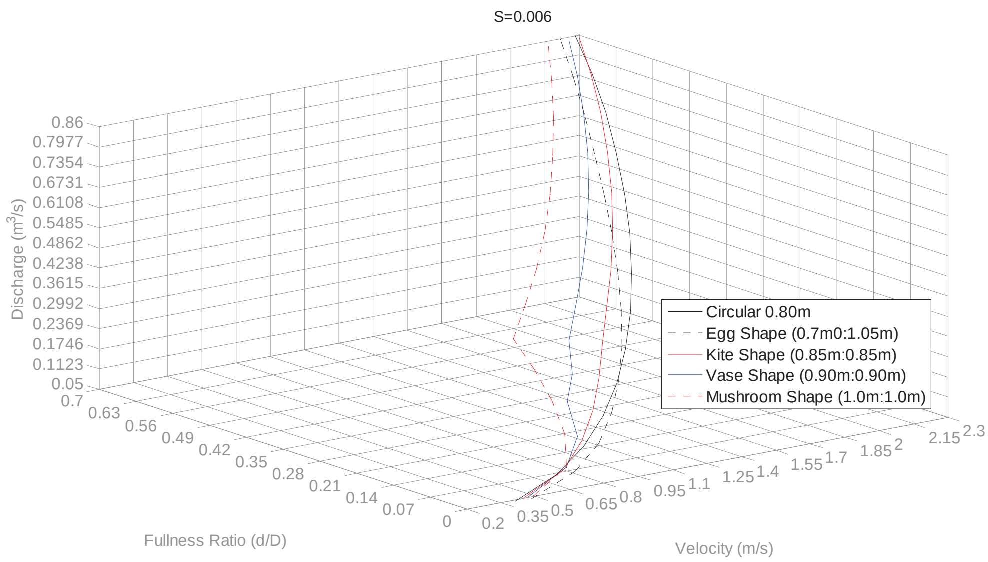


Figure 5.12.d 3D relation among flow discharge, fullness ratio, and velocity in circular and non-circular pipes for slope S = 0.006.

5.4.3 Circular Pipe (1.5m) in Diameter vs. Three Slopes (0.001, 0.003, and 0.006)

In this section, there are three groups; these three groups aim to compare selected non-circular sections with a circular one of 1.5m diameter for three selected slopes of 0.001, 0.003, and 0.006 respectively.

Each of these three groups contains four figures of the following properties:

1- The relation between flow velocity ratio V_e/V_c (non-circular/circular) and discharge q. In this group of Figures/plots, the circular pipe will show its velocity ratio V_e/V_c as a horizontal line. In fact, this is intended in order to ease the relative comparison and observe the behavior for the rest of the sections.
2- The relation between flow velocity v and discharge q.
3- The relation between fullness ratio d/D and velocity v.
4- 3D relation among the velocity v, discharge q, and fullness ratio d/D.

A. Figures 5.13 (a - d) Non-Circular Sections in Comparison with a Circular Pipe of 1.5m in Diameter for Slope S = 0.001

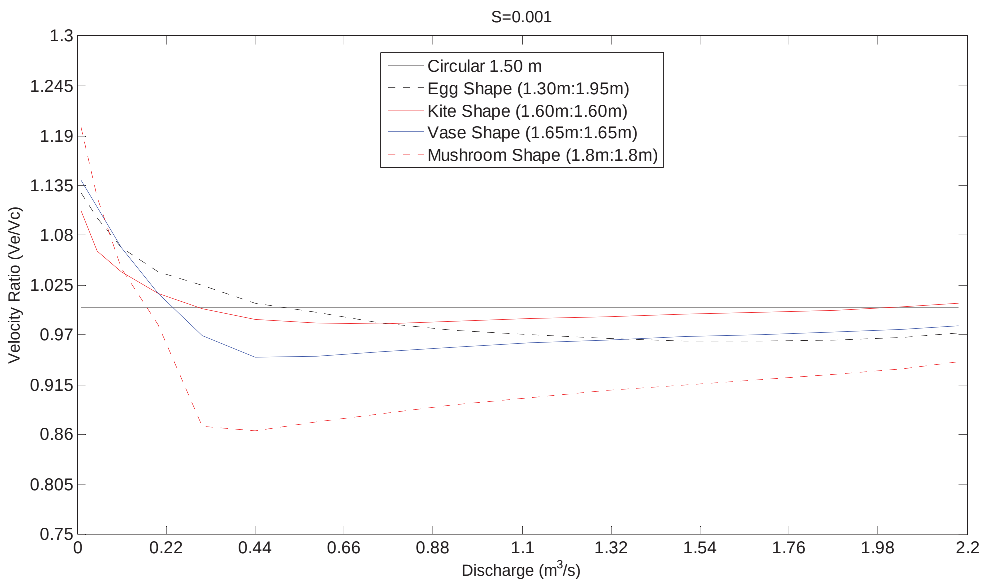


Figure 5.13.a The relation between flow velocity ratio V_e/V_c (non-circular/circular) and discharge for slope S = 0.001.

In Figure 5.13.a, it can be clearly seen that for the initial/relatively low discharge 0.011m^3/s, the overall trend for non-circular curves shows fluctuation with slight increase in velocity ratio V_e/V_c in comparison to the velocity ratio of the circular section.

Starting with Mushroom shaped section, the curve rose up to 1.20 in 0.0011m^3/s then gradually declined to 1 in 0.18 m^3/s, and continued to decrease but gently to 0.864 in 0.30 m^3/s with a little increase to 0.94 in 2.18 m^3/s.

Followed by Egg shape, the curve which rose to 1.127 in 0.011m^3/s and dropped to 1 in 0.56 m^3/s, then, continued to decrease to 0.935 in 0.008 m^3/s with a little increase to 0.972 in 2.18 m^3/s.

The last two curves (Vase and Kite shapes) increased to 1.14 and 1.107 respectively. The Vase shape curve dropped to 1 in 0.23 m^3/s, and continued to decrease but gently to 0.95 in 0.45 m^3/s with a little increase to 0.975 m^3/s, while the Kite shape decreased to 1 in 0.30 m^3/s, and dropped steeply to 0.85 m^3/s in 0.006 then showed gentle increase to 1in 1.98 m^3/s with a little increase to 1.005 in 2.18 m^3/s.

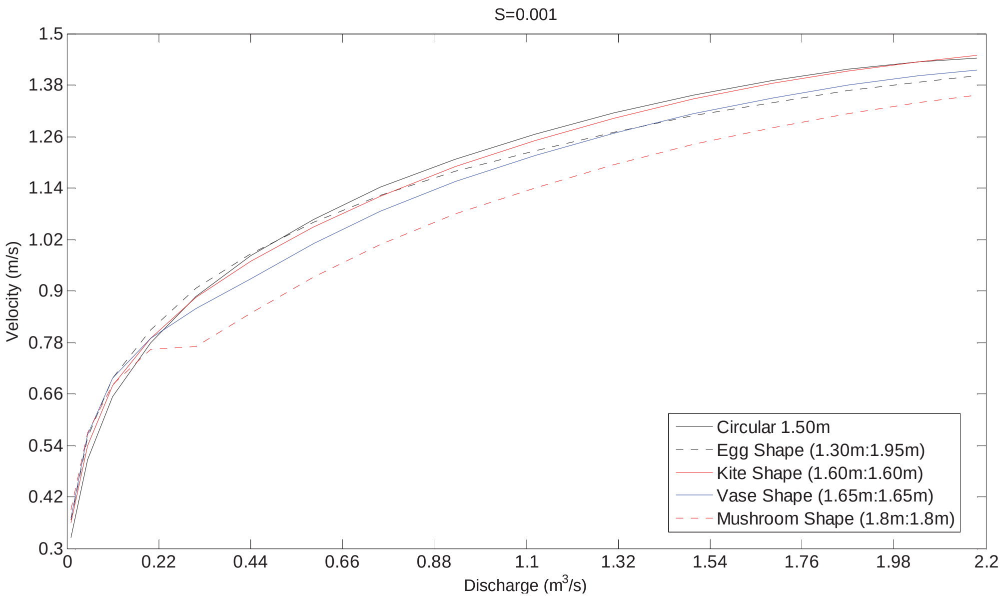


Figure 5.13.b Relation between flow velocity and discharge in circular and non-circular pipes for slope S = 0.001.

Figure 5.13.b indicates the variation in the velocity versus discharge for the circular and non-circular sections, all flow with slope of S = 0.001, and a range of discharge between 0.011 and 2.18m^3/s.

In non-circular pipes, for low flow discharges with fullness ratio less than around 25%, the overall trend of non-circular sections show slightly higher velocity in comparison with the circular one. After that, they show gradual decrease and fall below the circular curve with intersection points in different ranges.

The fact behind different curvature tendencies is that, each form of circular and non circular sections has different variation in the ratio of A/P. Thus, with the increase in discharge, the ratio A/P would increase in each non-circular section in a different way.

After the fullness ratio exceeds around 25%, the circular section shows a better performance regarding the velocity when compared with the other non-circular sections.

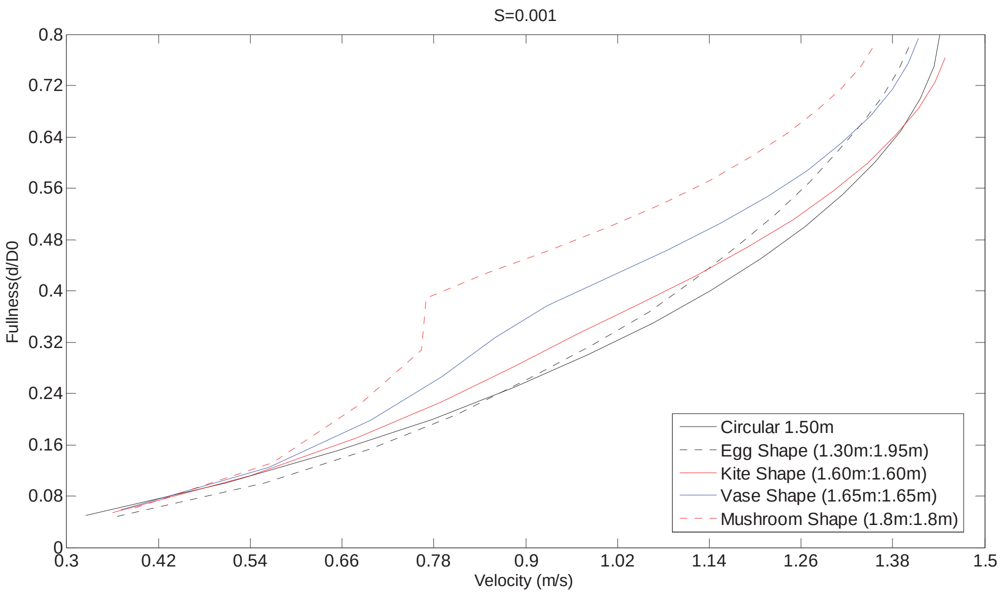


Figure 5.13.c The relation between fullness ratio and velocity in circular and non-circular pipes for slope S = 0.001.

In Figure 5.13.c, the relatively wide range of variation among the curves is related mainly to the difference in the depth of flow resulting from having different sections

(particularly the lower half of each non-circular section) when applying the same value of discharge for all sections alike.

The curve relevant to the Mushroom section shows sudden vertical increase where the fullness ratio is around 35%. Obviously, this is due to the sudden widening of the section at that height.

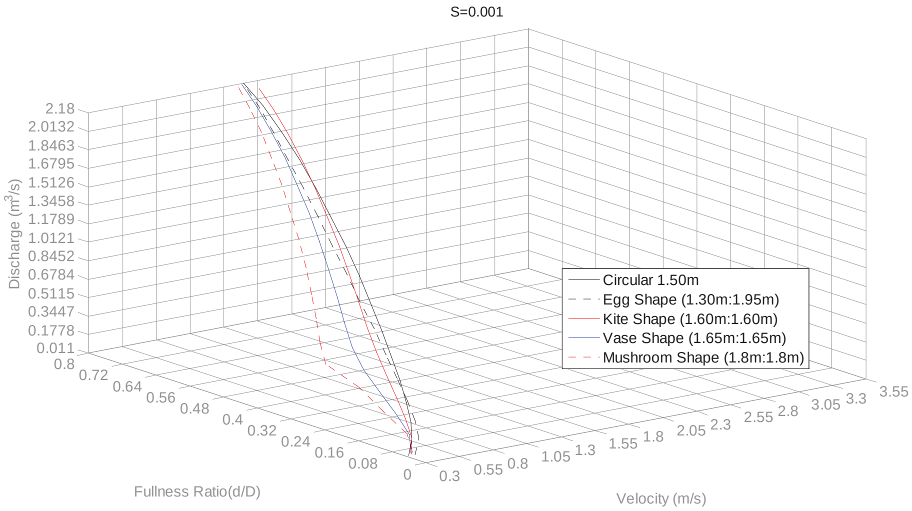


Figure 5.13.d 3D relation among flow discharge, fullness ratio, and velocity in circular and non-circular pipes for slope S = 0.001.

B. Figures 5.14 (a - d) Non-Circular Sections in Comparison with a Circular Pipe of 1.5m in Diameter for Slope S = 0.003

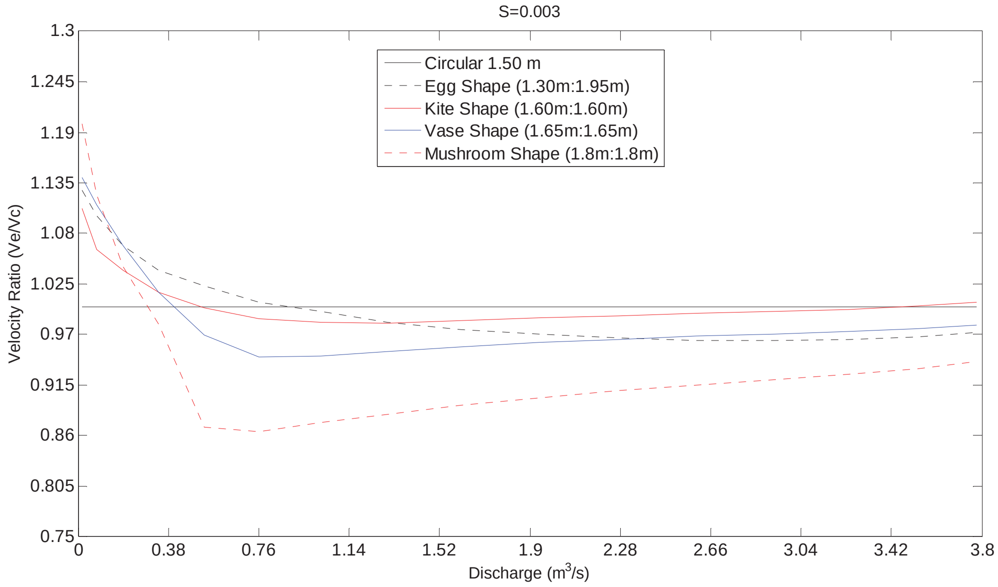


Figure 5.14.a The relation between flow velocity ratio V_e/V_c (non-circular/circular) and discharge for slope S = 0.003.

In Figure 5.14.a, the comparison results have the same velocity ratio V_e/V_c in comparison with the previous case S = 0.001(explained in Figure 5.13.a). The only difference is the range of discharge which is between 0.019 and 3.78 m^3/s.

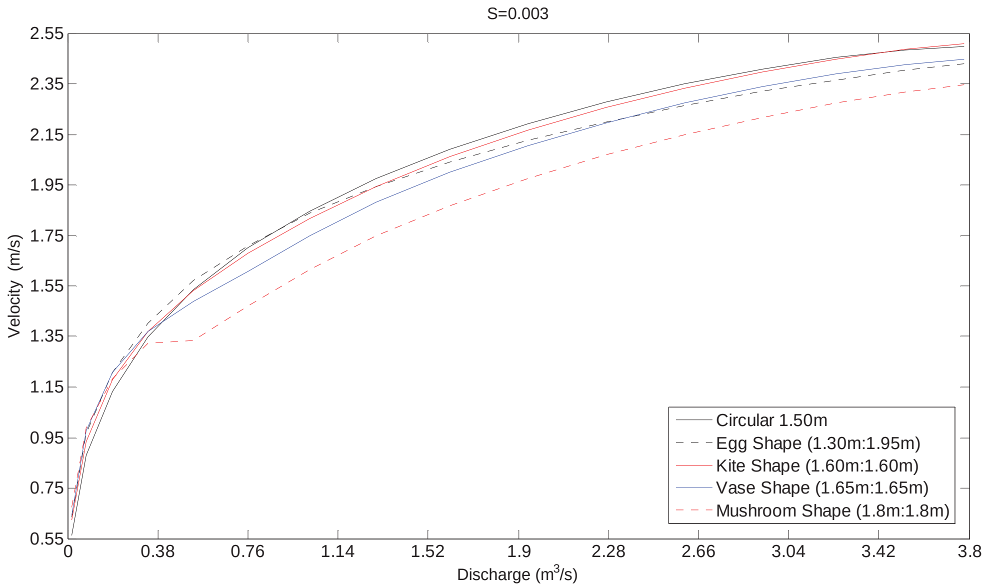


Figure 5.14.b Relation between flow velocity and discharge in circular and non-circular pipes for slope S = 0.003.

Figure 5.14.b indicates the variation in the velocity versus discharge for the circular and non-circular sections, all flow with slope of S = 0.003, and a range of discharge between 0.019 and 3.78 m^3/s. The comparison relatively shows similar result of curve tendencies in comparison with the previous case S = 0.001(explained in Figure 5.13.b). The only difference is the range of the discharge along with the velocity.

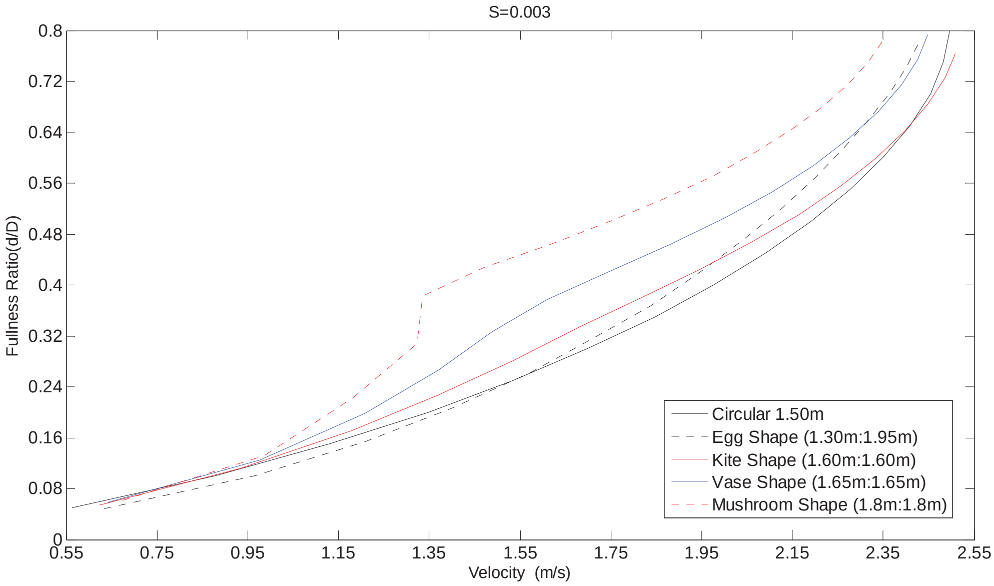


Figure 5.14.c The relation between fullness ratio and velocity in circular and non-circular pipes for slope S = 0.003.

In Figure 5.14.c, the comparison result relatively shows the same curve tendencies in comparison with the previous case S = 0.001(explained in Figure 5.13.c). The only difference is the range of the velocity.

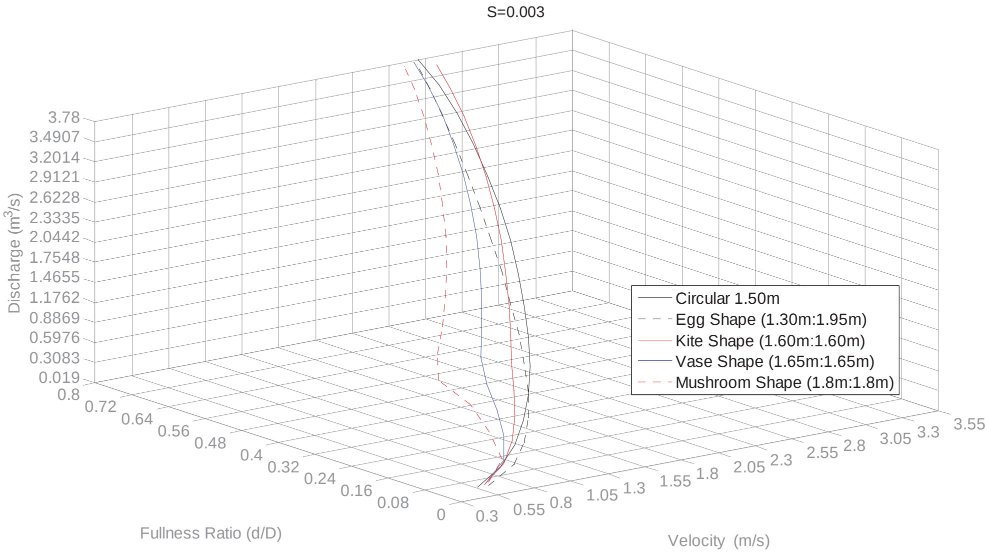


Figure 5.14.d 3D relation among flow discharge, fullness ratio, and velocity in circular and non-circular pipes for slope S = 0.003.

C. Figures 5.15 (a - d) Non-Circular Sections in Comparison with a Circular Pipe of 0.8m in Diameter for Slope S = 0.006

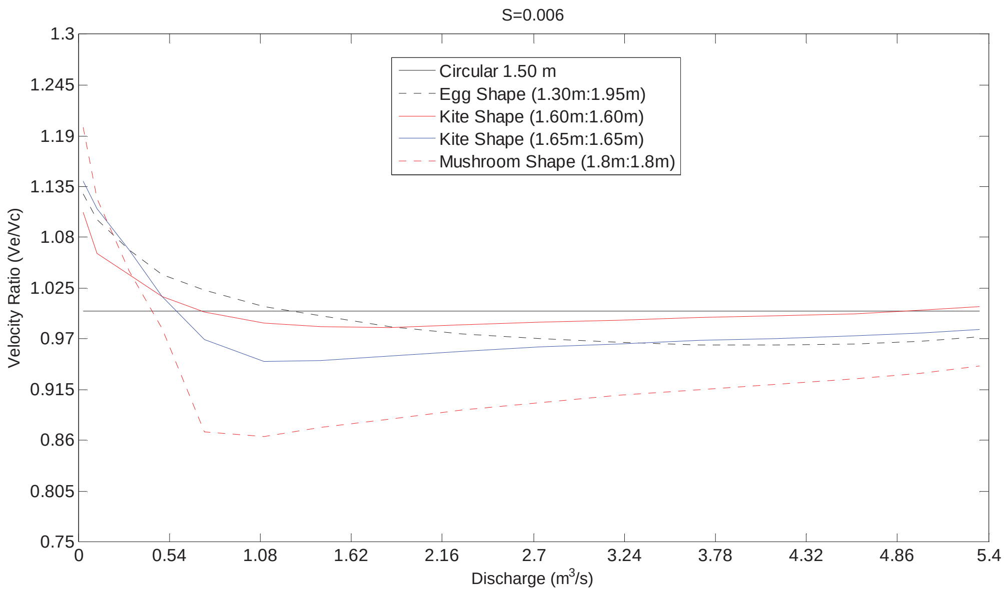


Figure 5.15.a The relation between flow velocity ratio Ve/Vc (non-circular/circular) and discharge for slope S = 0.006.

In Figure 5.15.a, the comparison results have the same velocity ratio V_e/V_c in comparison with the previous case S = 0.001(explained in Figure 5.13.a). The only difference is the range of discharge which is between 0.03 and 5.35 m^3/s.

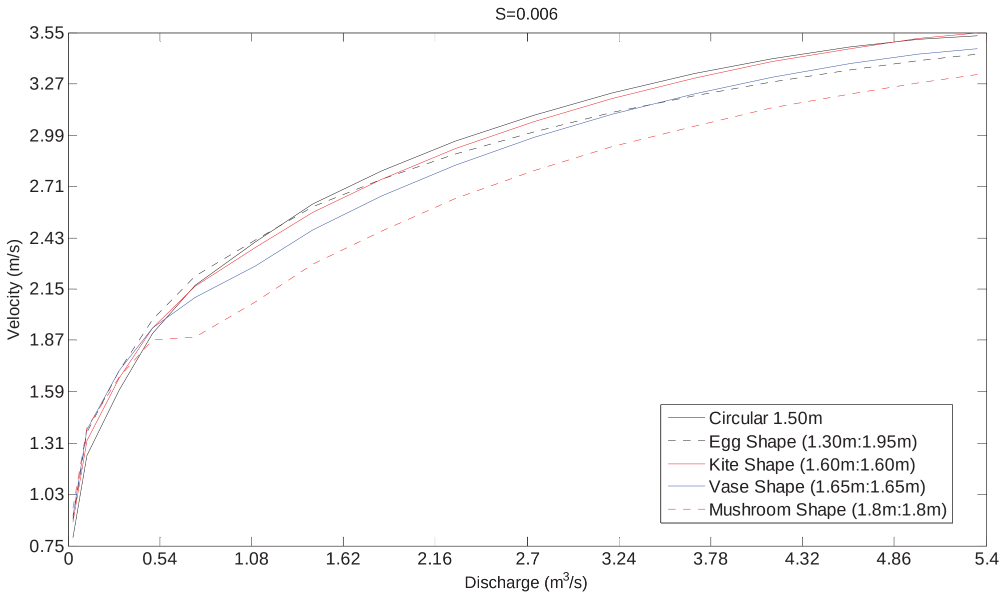


Figure 5.15.b Relation between flow velocity and discharge in circular and non-circular pipes for slope S = 0.006.

Figure 5.15.b indicates the variation in the velocity versus discharge for the circular and non-circular sections, all flow with slope of S = 0.006, and a range of discharge between 0.03 and 5.35 m^3/s. The comparison relatively shows similar result of curve tendencies in comparison with the previous case S = 0.001(explained in Figure 5.13.b). The only difference is the range of the discharge along with the velocity.

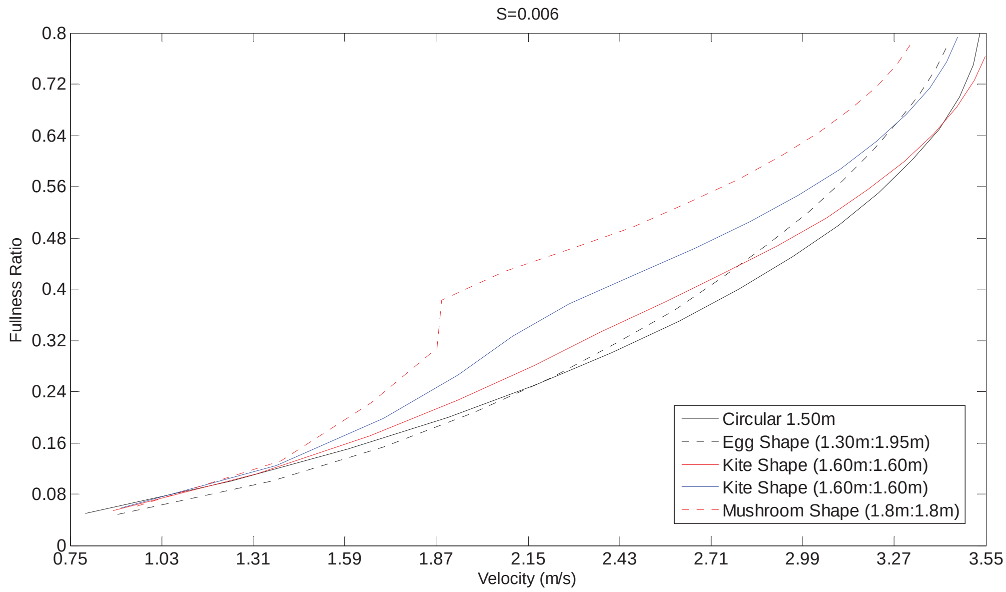


Figure 5.15.c The relation between fullness ratio and velocity in circular and non-circular pipes for slope S = 0.006.

In Figure 5.15.c, the comparison result shows relatively the same curve tendencies in comparison with the previous case S = 0.001(explained in Figure 5.13.c). The only difference is the range of the velocity.

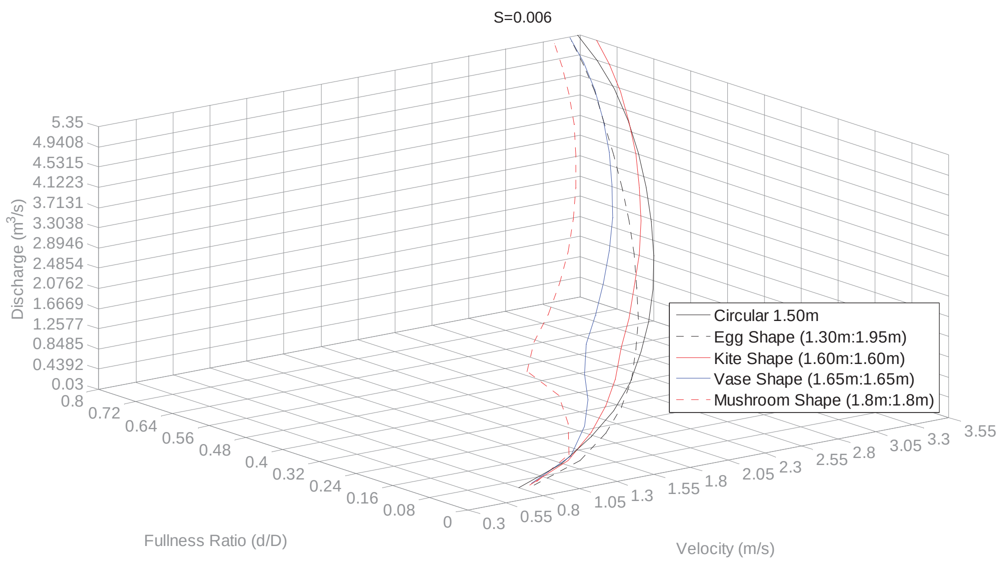


Figure 5.15.d 3D relation among flow discharge, fullness ratio, and velocity in circular and non-circular pipes for slope S = 0.006.

5.5 Comparing Flow Velocity between Circular and Non-Circular Pipes for Slopes 0.001-0.006.

In this section, there are four groups, where each group presents three Figures. These four groups are:

A- Circular Sections in Comparison with an Egg-Shaped section for Slopes of 0.001 to 0.006 with 0.001 increasing steps.

B- Circular Sections in Comparison with a Kite section for Slopes of 0.001 to 0.006 with 0.001 increasing steps.

C- Circular Sections in Comparison with a Vase section for Slopes of 0.001 to 0.006 with 0.001 increasing steps.

D- Circular Sections in Comparison with a Mushroom section for Slopes of 0.001 to 0.006 with 0.001 increasing steps.

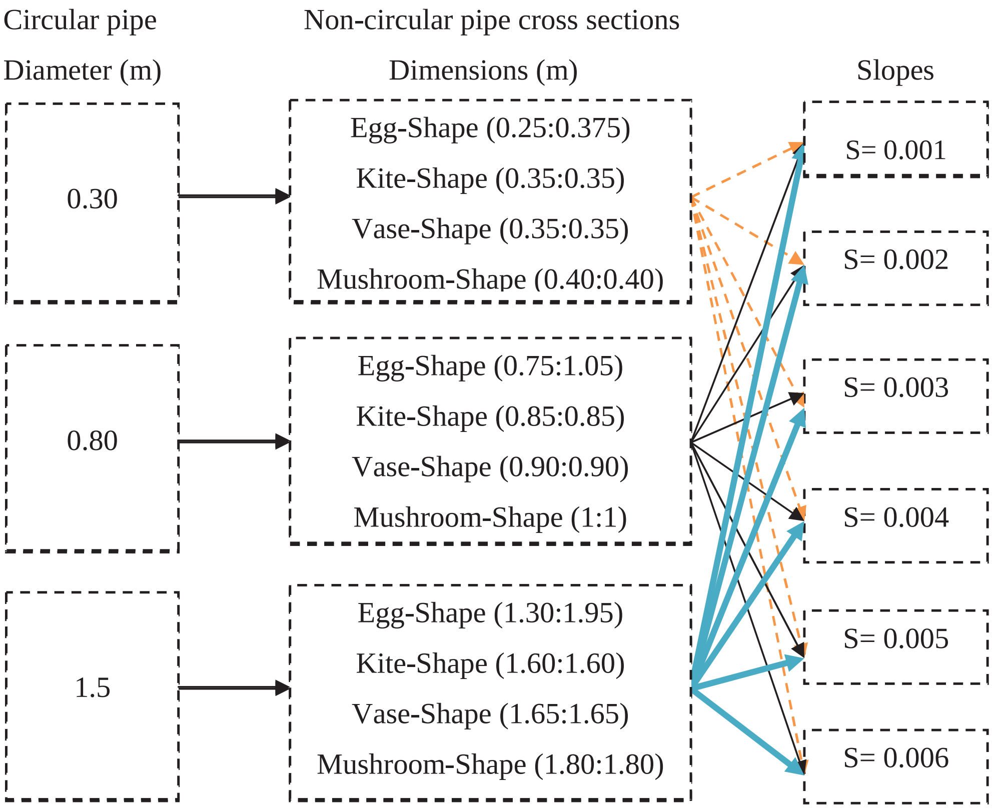


Figure 5.16 Sketch of the plan for the numeric comparison process between circular and non-circular sections for six different slopes with 0.001 increments.

Each of these four groups contains repeats the comparison for three circular diameters of 0.3m, 0.8m, and 1.5m respectively. As explained previously, the equivalent cross sectional area of the non-circular section was selected accordingly for the same increasing discharge values.

5.5.1 Comparison in the Effect of Slope Increase on Both Circular and Egg-Shaped Sections

In this section, velocity versus fullness ratio plots are produced to compare the behavior of circular section with the egg-shaped one for six increasing steps of the slope, starting from 0.001 to 0.006 with 0.001 step increase. This process was repeated three times for circular pipes of 0.3, 0.8, and 1.5m along with the relevant egg-shapes, as shown in Figures (5.17.a, 5.17.b, and 5.17.c).

In these three figures, as explained previously in section 5.1, increasing steps of fullness ratio were applied on the circular pipe of a particular diameter, and the relevant discharge and velocity values were found. These discharge values were recorded, and then, were considered to flow in the egg-shaped section with new values found for the velocity and fullness ratio.

It should be noted that in the three Figures explained in the previous paragraph, the scales had to be different for each selected diameter, and accordingly, the visual observation and comparison should be performed.

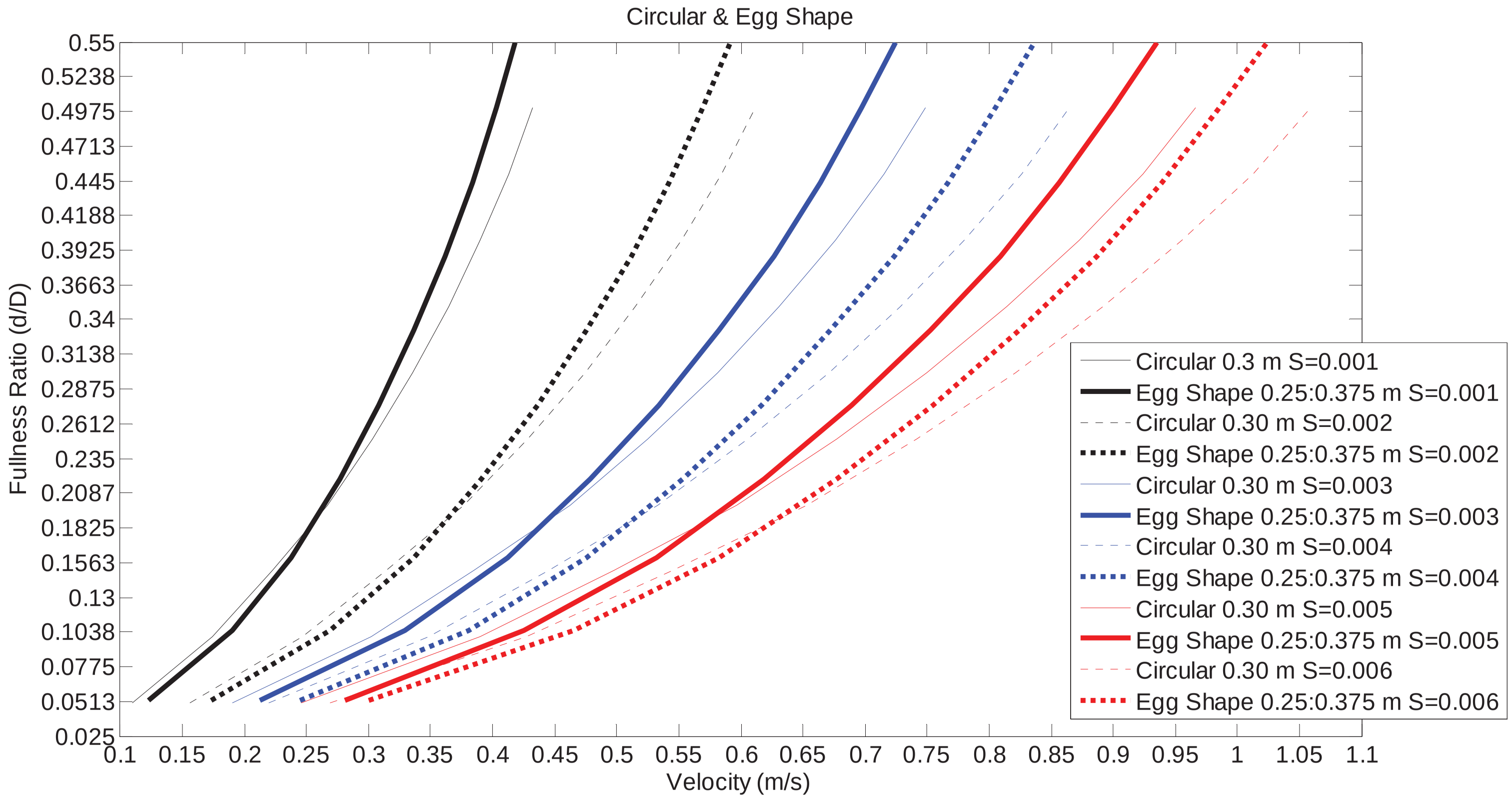


Figure 5.17.a Relation between fullness ratio and velocity in circular pipe of 0.3m Dia. and egg shape section 0.25m: 0.375m applied on slopes from 0.001 to 0.006.

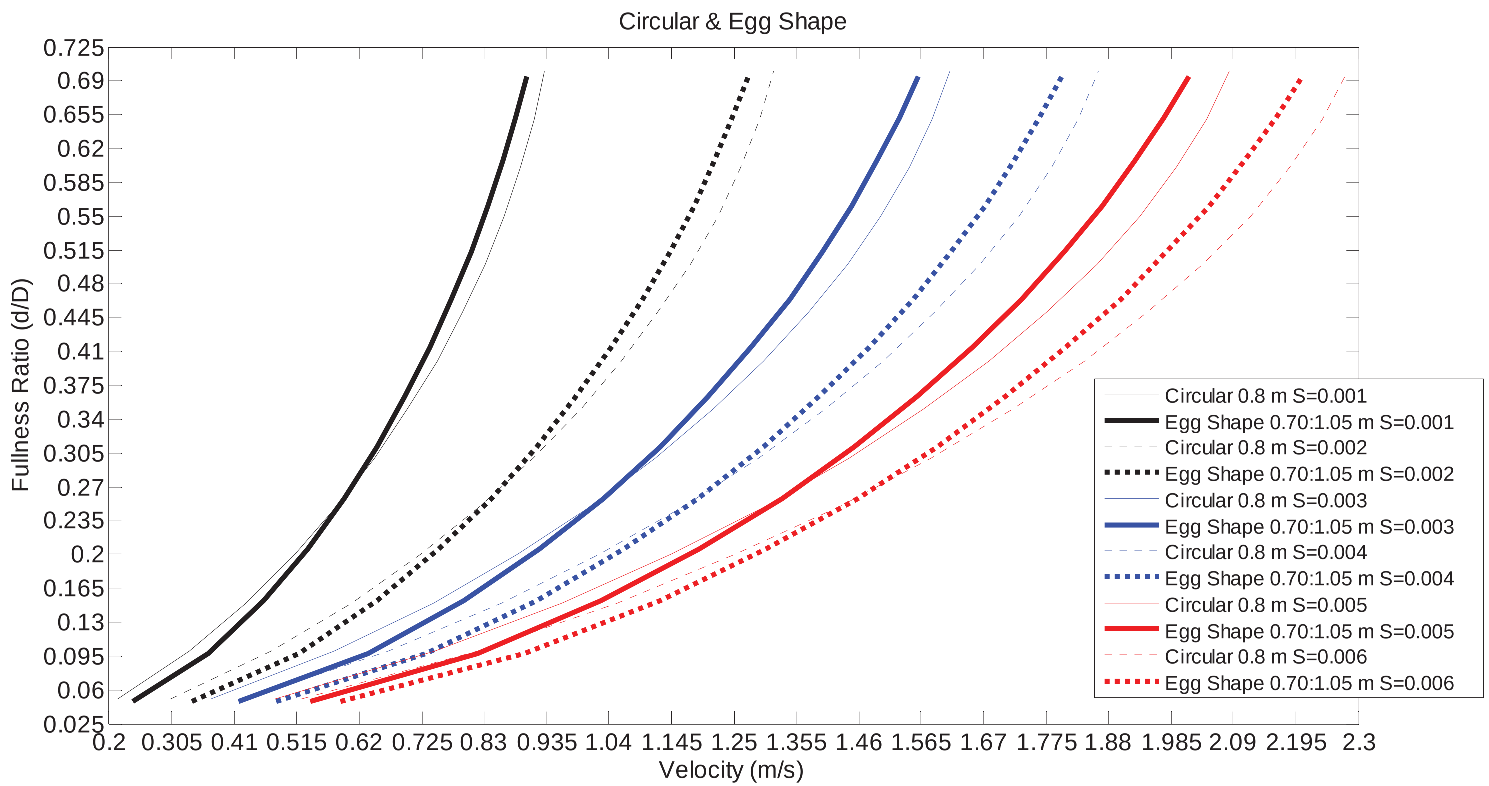
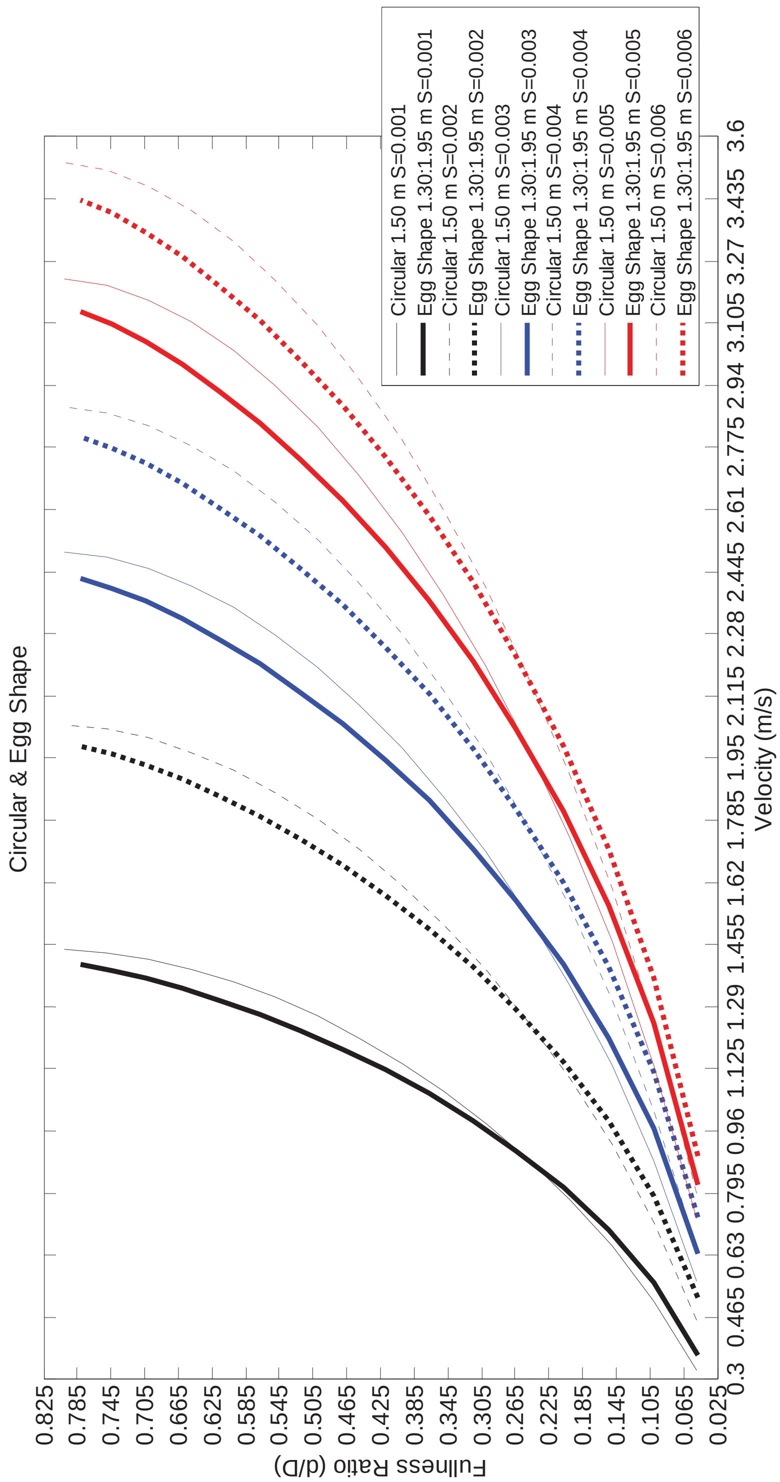


Figure 5.17.b Relation between fullness ratio and velocity in circular pipe of 0.80m Dia. and egg shape section 0.70m: 1.05m applied on slopes from 0.001 to 0.006.


Circular & Egg Shape
Fullness Ratio (d/D)
Velocity (m/s)
0.825
0.785
0.745
0.705
0.665
0.625
0.585
0.545
0.505
0.465
0.425
0.385
0.345
0.305
0.265
0.225
0.185
0.145
0.105
0.065
0.025
0.3 0.465 0.63 0.795 0.96 1.125 1.29 1.455 1.62 1.785 1.95 2.115 2.28 2.445 2.61 2.775 2.94 3.105 3.27 3.435 3.6
Circular 1.50 m S=0.001
Egg Shape 1.30:1.95 m S=0.001
Circular 1.50 m S=0.002
Egg Shape 1.30:1.95 m S=0.002
Circular 1.50 m S=0.003
Egg Shape 1.30:1.95 m S=0.003
Circular 1.50 m S=0.004
Egg Shape 1.30:1.95 m S=0.004
Circular 1.50 m S=0.005
Egg Shape 1.30:1.95 m S=0.005
Circular 1.50 m S=0.006
Egg Shape 1.30:1.95 m S=0.006

The comparison shows, in general as expected, that the egg-shaped section has relatively higher velocity for low flows and lower velocity for higher flows. However, the intersection point where the velocity in egg-shaped changes from being higher than the one in circular pipes into being lower, seems be of the same value for a particular selected pipe diameter while increasing the slope.

Figure 5.17.a shows the results of the comparison for circular pipes of 0.3m in diameter in along with the relevant egg-shaped section, repeated for slopes from 0.001 to 0.006 with increasing steps of 0.001. Figures 5.17.b and 5.17.c represent a repetition to the process with the consideration of the circular pipe diameter to be 0.8 and 1.5m consecutively. The following are the curves intersection points versus fullness ratio:

a- The intersection is at 18.94% fullness ratio intersection for 0.3m diameter
b- The intersection is at 26.61% fullness ratio intersection for 0.8m diameter
c- The intersection is at 24% fullness ratio intersection for 1.5m diameter

It is not possible to conclude on the difference in the intersection point among the results of the investigations three selected diameters. This is due to the difference in the maximum allowed fullness ratio for each diameter. From the hydraulic point of view, the comparison may be efficient only when the maximum fullness ratio is proposed to be the same, which is not the case in reality regarding the execution of sewer projects.

For the same pipe circular diameter taken as a reference, the increase in the velocity appears to be decreasing exponentially with the linear increase of the slope.

5.5.2 Comparison in the Effect of Slope Increase on Both Circular and Kite-Shaped Sections

Figure 5.18.a shows the results of the comparison for circular pipes of 0.3m in diameter in along with the relevant kite-shaped section, repeated for slopes from 0.001 to 0.006 with increasing steps of 0.001. Figures 5.18.b and 5.18.c represent a repetition to the process with the consideration of the circular pipe diameter to be 0.8 and 1.5m consecutively.

In figure 5.18.a, 5.18.b, and 5.18.c, the intersection points in each pair of the curves seems to be more than one location. This is due to the similarity in flow velocity for a particular fullness ratio despite that the flow discharge in these intersection points is not the same. Obviously, the reason for the difference in discharge is the difference in the shape of the cross section.

The following are the curves intersection points versus fullness ratio regarding one location that indicates low flow conditions (fullness ratio less than 25%):

a- The intersection is at 24.02% fullness ratio intersection for 0.3m diameter

b- The intersection is at 8.21% fullness ratio intersection for 0.8m diameter

c- The intersection is at 9.54% fullness ratio intersection for 1.5m diameter

It is not possible to conclude on the difference in the intersection point among the results of the investigations three selected diameters. This is due to the difference in the maximum allowed fullness ratio for each diameter. From the hydraulic point of view, the comparison may be efficient only when the maximum fullness ratio is proposed to be the same, which is not the case in reality regarding the execution of sewer projects.

For the same pipe circular diameter taken as a reference, the increase in the velocity appears to be decreasing exponentially with the linear increase of the slope.

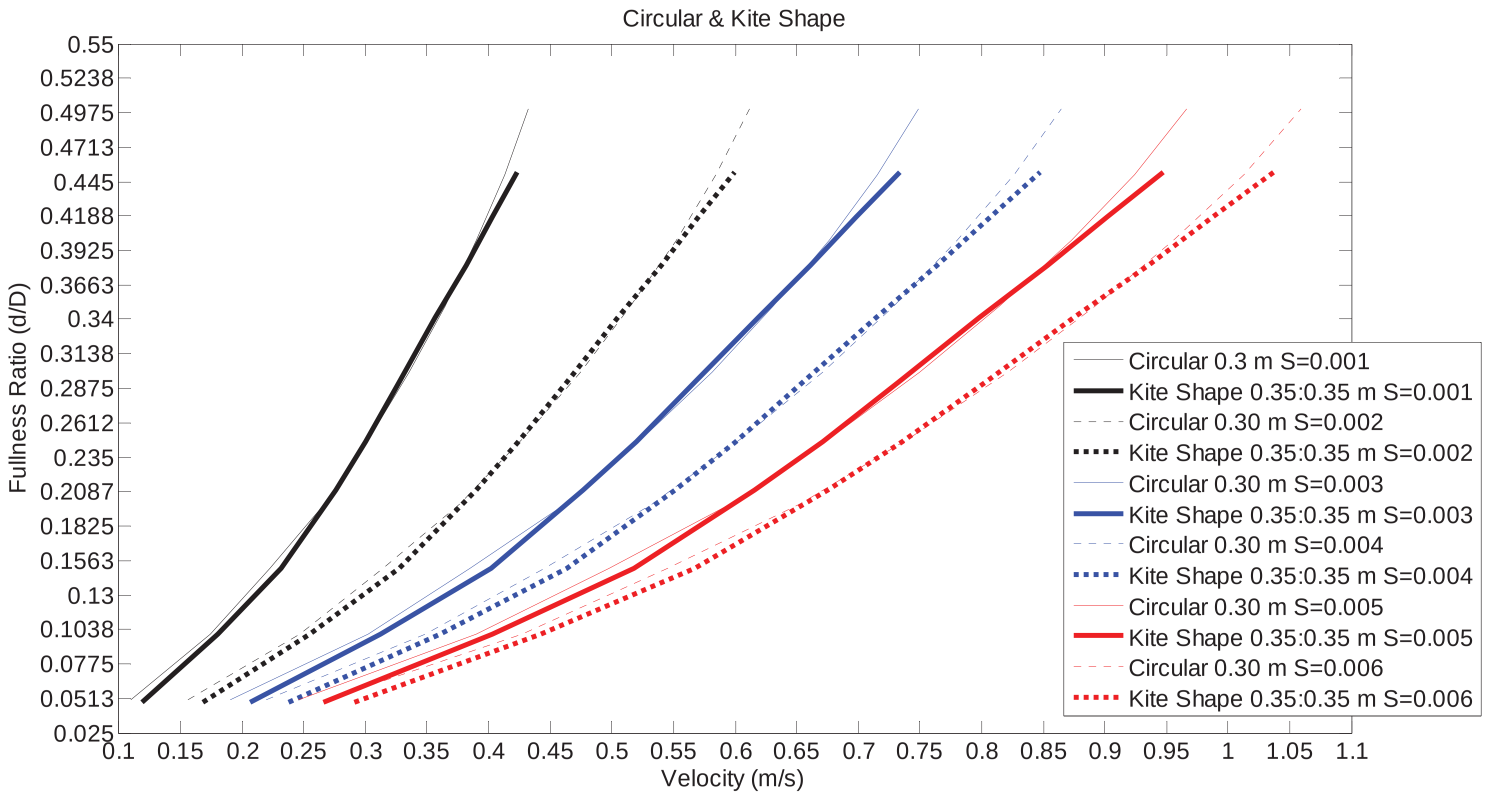


Figure 5.18.a Relation between fullness ratio and velocity in circular pipe of 0.3m Dia. and kite shape section 0.35m: 0.35m applied on slopes from 0.001 to 0.006.

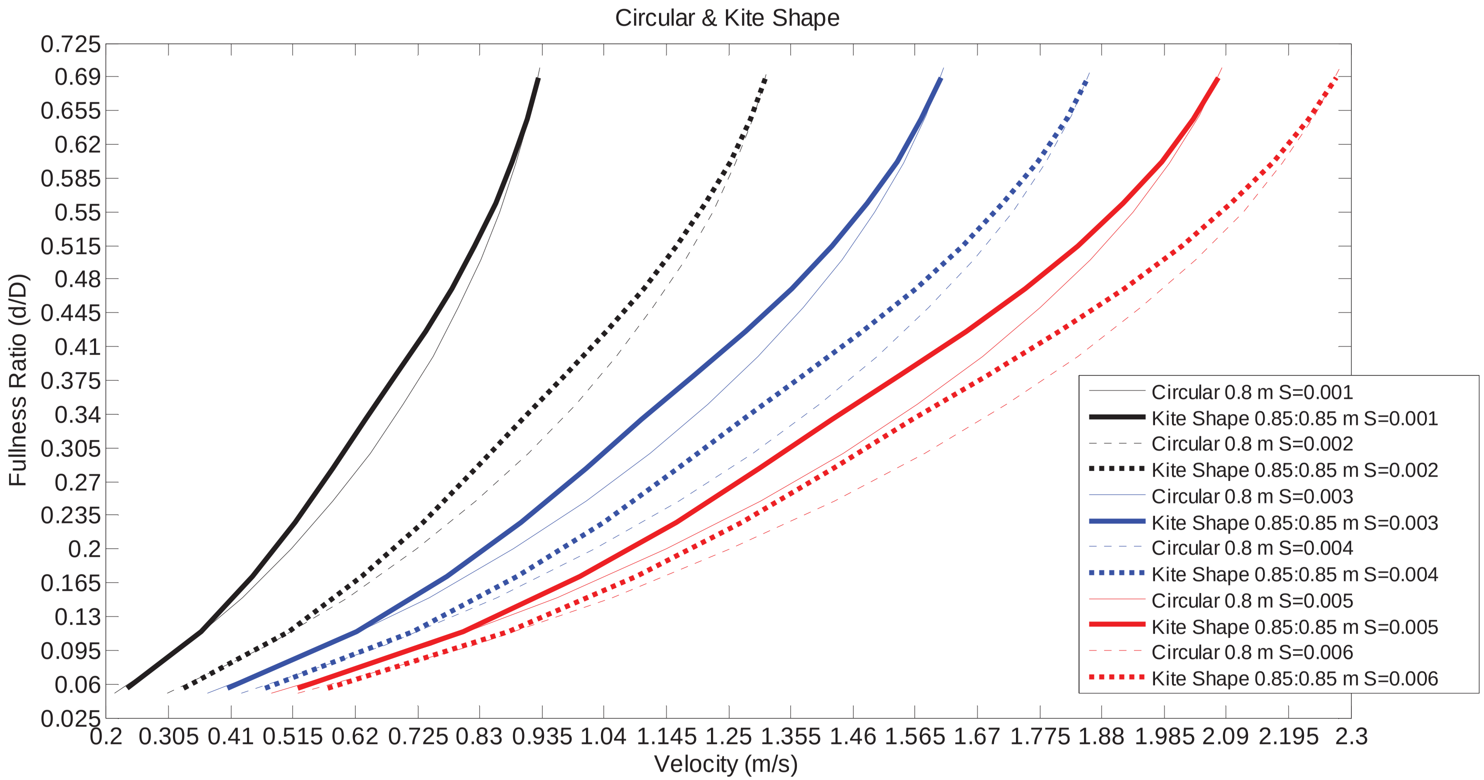


Figure 5.18.b Relation between fullness ratio and velocity in circular pipe of 0.8m Dia. and kite shape section 0.85m: 0.85m applied on slopes from 0.001 to 0.006.

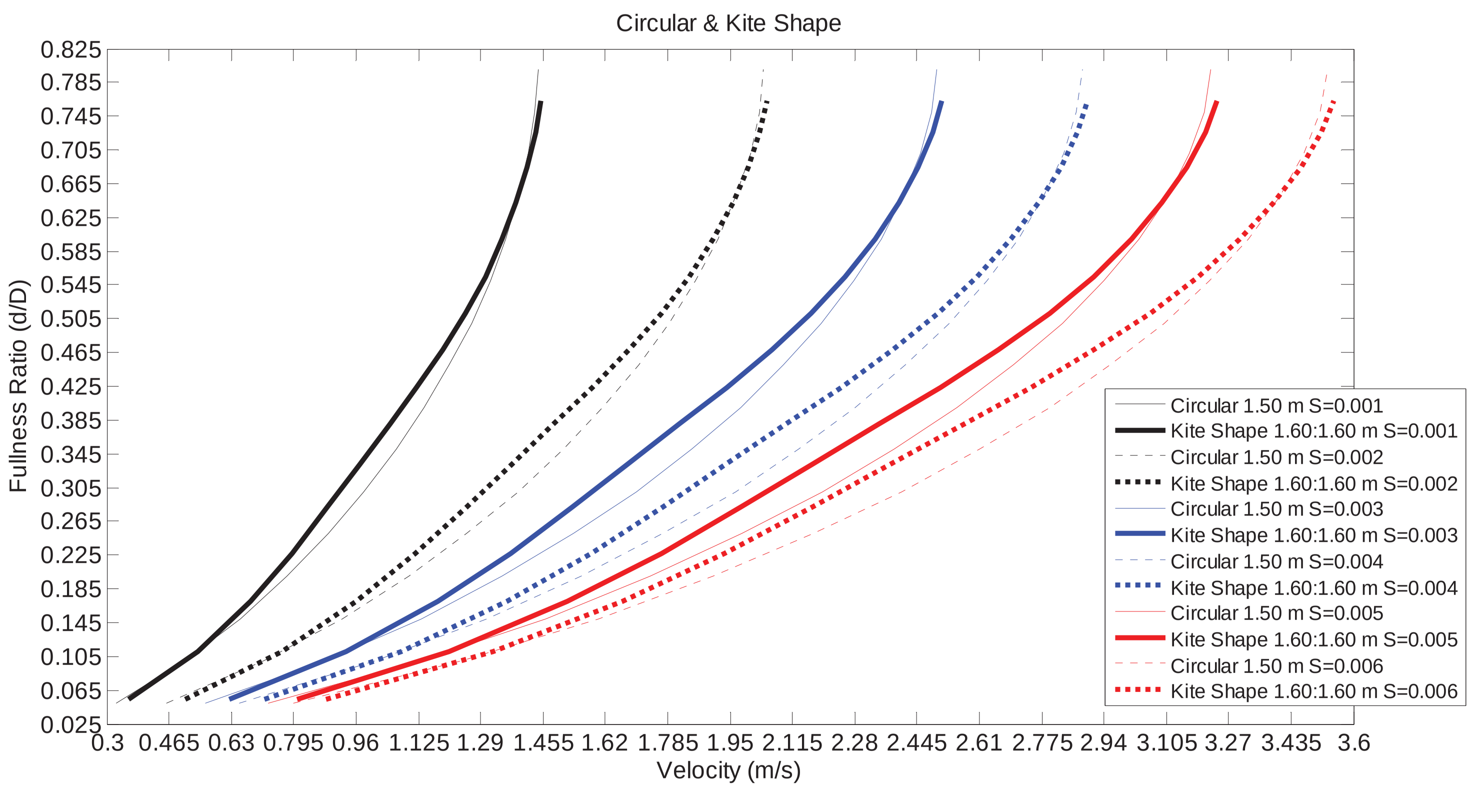


Figure 5.18.c Relation between fullness ratio and velocity in circular pipe of 1.5m Dia. and kite shape section 1.60m: 1.60m applied on slopes from 0.001 to 0.006.

5.5.3 Comparison in the Effect of Slope Increase on Both Circular and Vase-Shaped Sections

Figure 5.19.a shows the results of the comparison for circular pipes of 0.3m in diameter in along with the relevant vase-shaped section, repeated for slopes from 0.001 to 0.006 with increasing steps of 0.001. Figures 5.19.b and 5.19.c represent a repetition to the process with the consideration of the circular pipe diameter to be 0.8 and 1.5m consecutively. The following are the curves intersection points versus fullness ratio:

a- The intersection is at 13.38% fullness ratio intersection for 0.3m diameter
b- The intersection is at 9.1 % fullness ratio intersection for 0.8m diameter
c- The intersection is at 8.07% fullness ratio intersection for 1.5m diameter

It is not possible to conclude on the difference in the intersection point among the results of the investigations three selected diameters. This is due to the difference in the maximum allowed fullness ratio for each diameter. From the hydraulic point of view, the comparison may be efficient only when the maximum fullness ratio is proposed to be the same, which is not the case in reality regarding the execution of sewer projects.

For the same pipe circular diameter taken as a reference, the increase in the velocity appears to be decreasing exponentially with the linear increase of the slope.

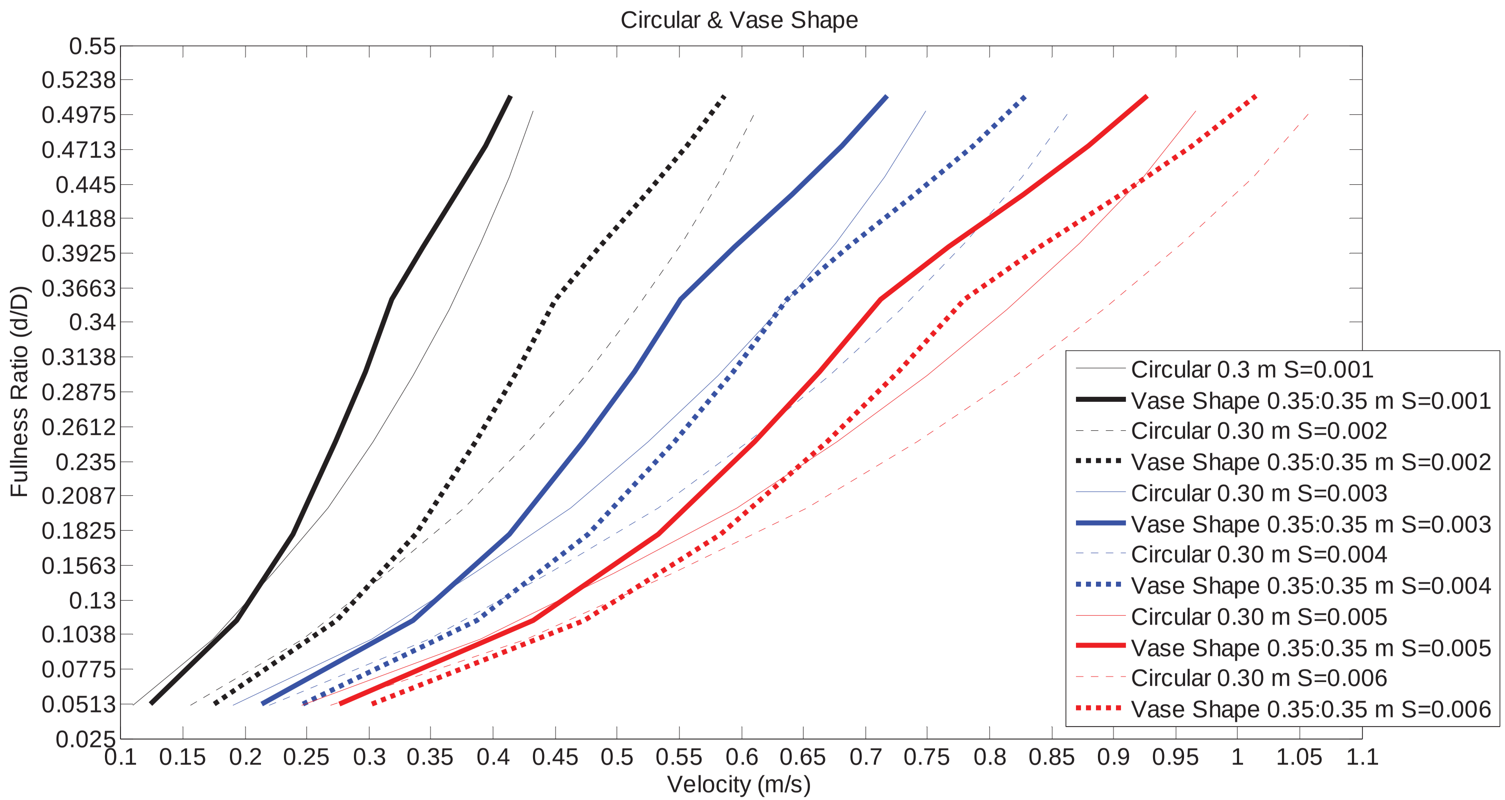


Figure 5.19.a Relation between fullness ratio and velocity in circular pipe of 0.3m Dia. and vase shape section 0.35m: 0.35m applied on slopes from 0.001 to 0.006.

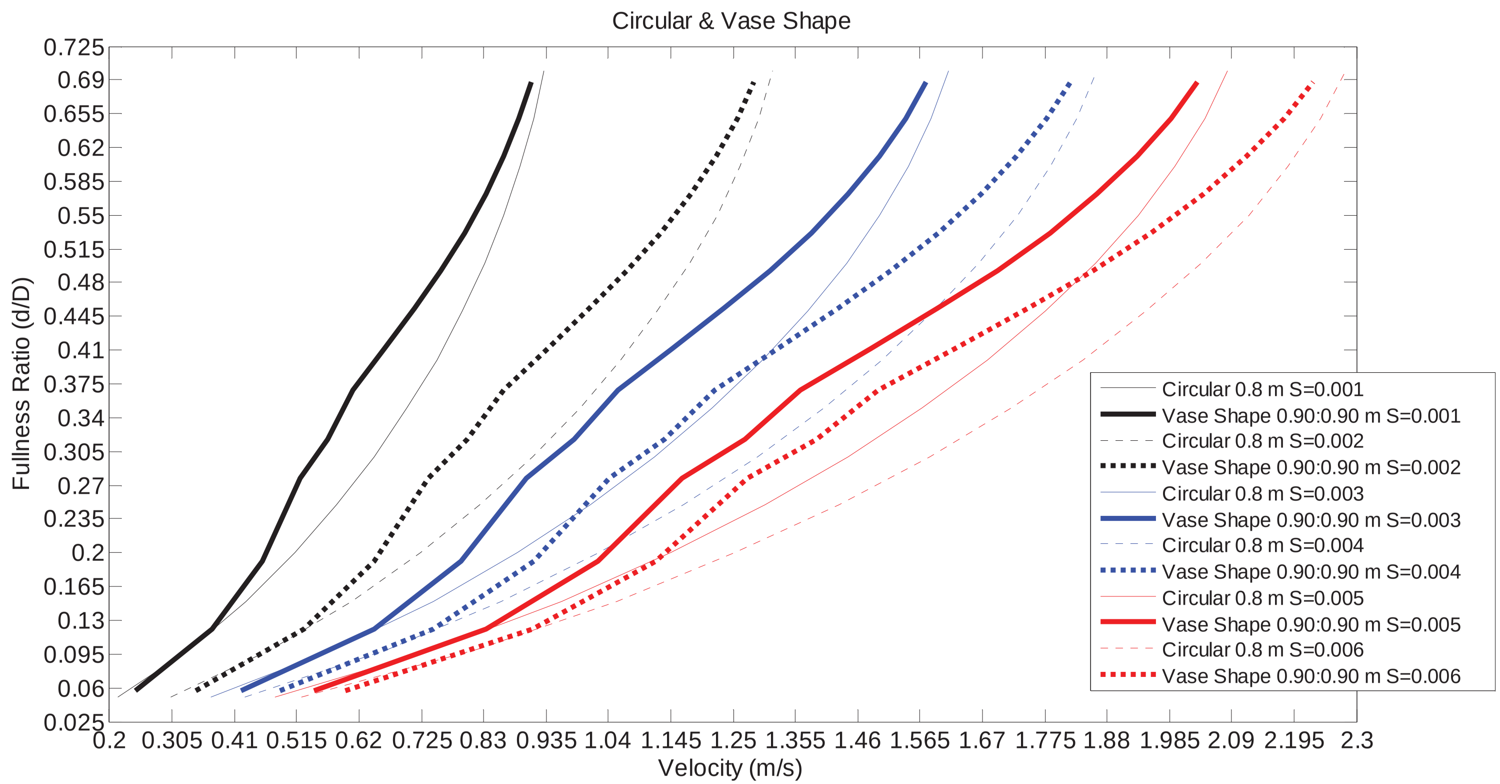


Figure 5.19.b Relation between fullness ratio and velocity in circular pipe of 0.8m Dia. and vase shape section 0.90m: 0.90m applied on slopes from 0.001 to 0.006.

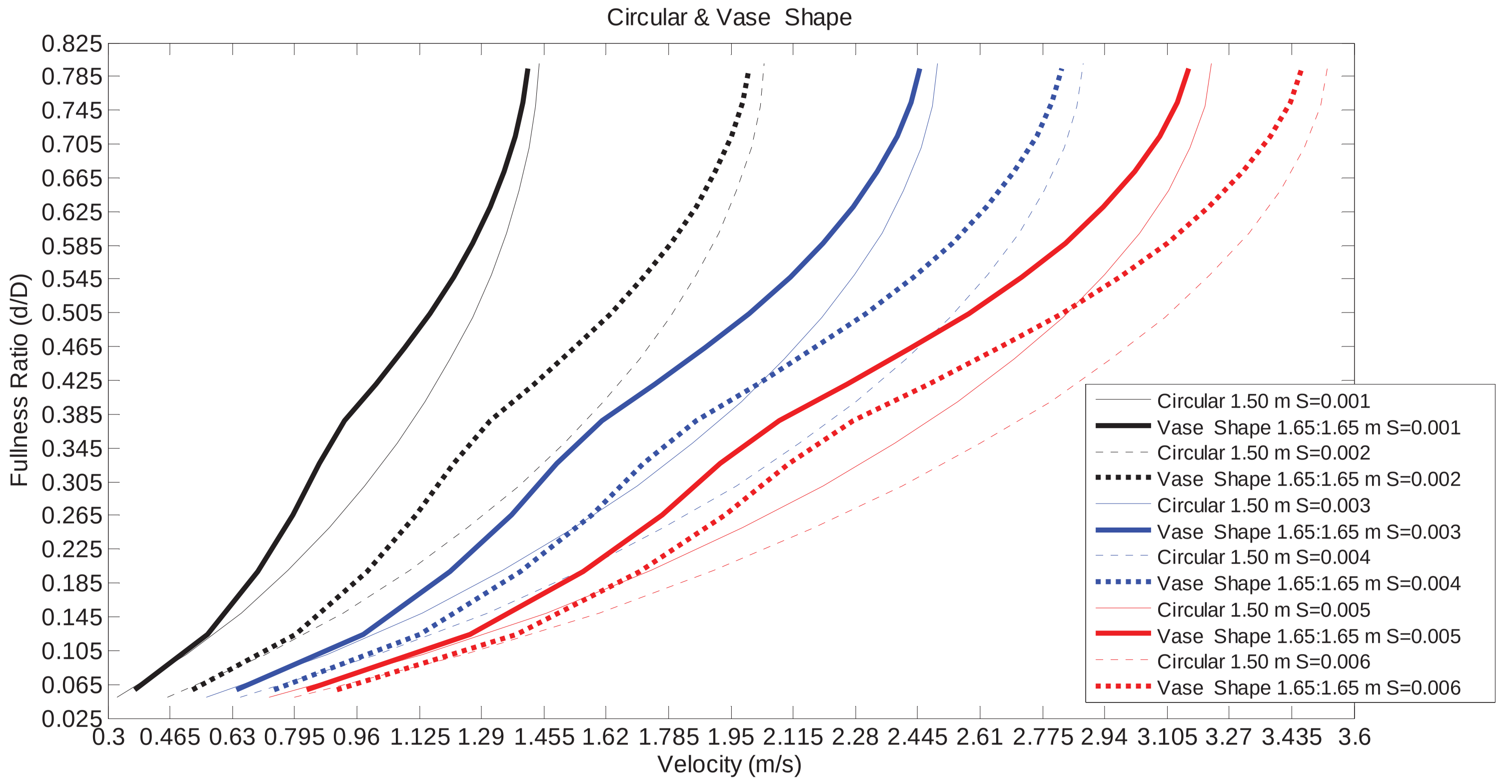


Figure 5.19.c Relation between fullness ratio and velocity in circular pipe of 1.5m Dia. and vase shape section 1.65m: 1.65m applied on slopes from 0.001 to 0.006.

5.5.4 Comparison in the Effect of Slope Increase on Both Circular and Mushroom-Shaped Sections

Figure 5.20.a shows the results of the comparison for circular pipes of 0.3m in diameter in along with the relevant mushroom-shaped section, repeated for slopes from 0.001 to 0.006 with increasing steps of 0.001. Figures 5.20.b and 5.20.c represent a repetition to the process with the consideration of the circular pipe diameter to be 0.8 and 1.5m consecutively. The following are the curves intersection points versus fullness ratio:

a- The intersection is at 12.86% fullness ratio intersection for 0.3m diameter
b- The intersection is at 9.54 % fullness ratio intersection for 0.8m diameter
c- The intersection is at 8.25 % fullness ratio intersection for 1.5m diameter

It is not possible to conclude on the difference in the intersection point among the results of the investigations three selected diameters. This is due to the difference in the maximum allowed fullness ratio for each diameter. From the hydraulic point of view, the comparison may be efficient only when the maximum fullness ratio is proposed to be the same, which is not the case in reality regarding the execution of sewer projects.

For the same pipe circular diameter taken as a reference, the increase in the velocity appears to be decreasing exponentially with the linear increase of the slope. Also, it is observed that the ratio of increasing the velocity while increasing the slope in all four groups of comparison (i.e. circular with egg-shaped, kite, vase, and mushroom) were the same.

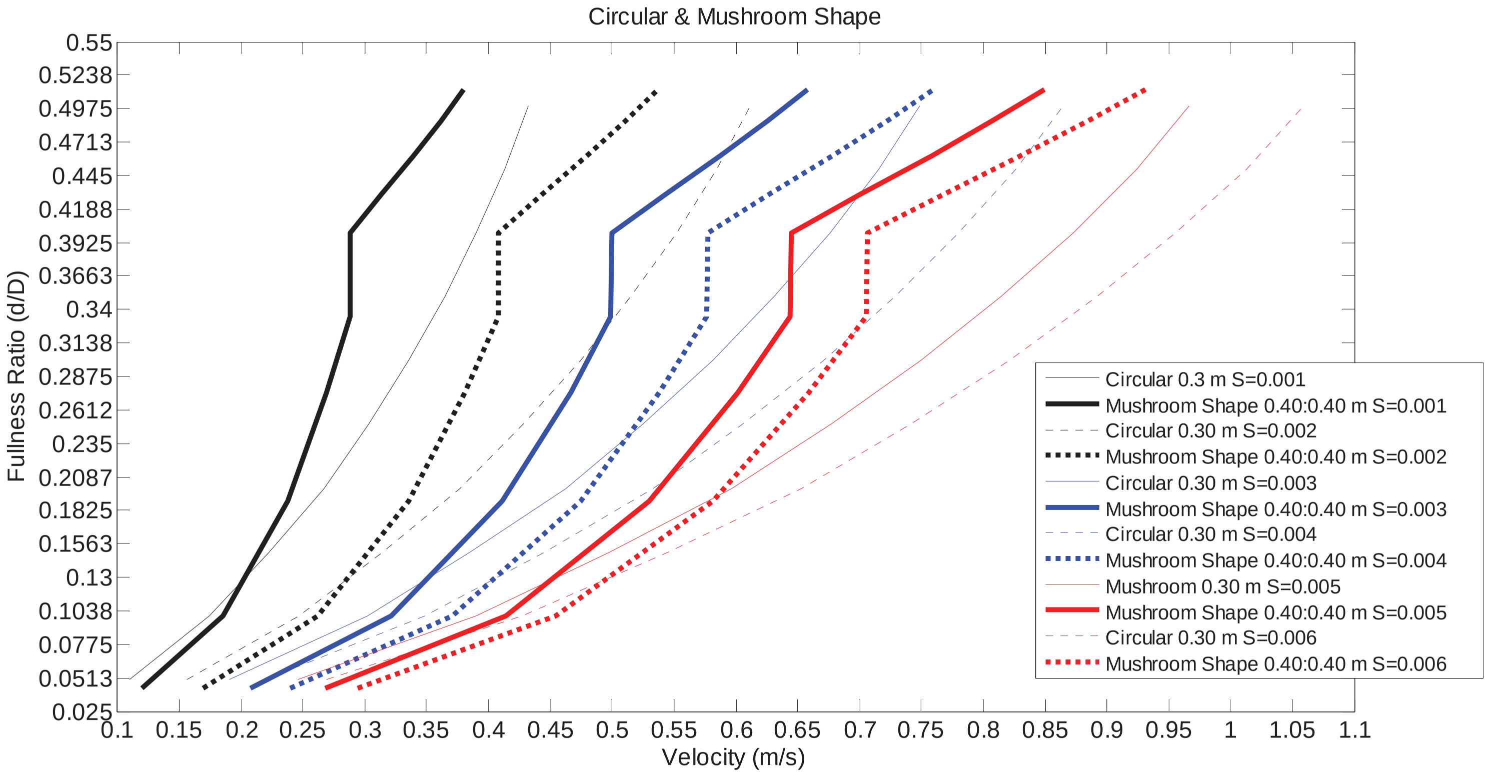


Figure 5.20.a Relation between fullness ratio and velocity in circular pipe of 0.3m Dia. and mushroom shape section 0.40m: 0.40m applied on slopes from 0.001 to 0.006.

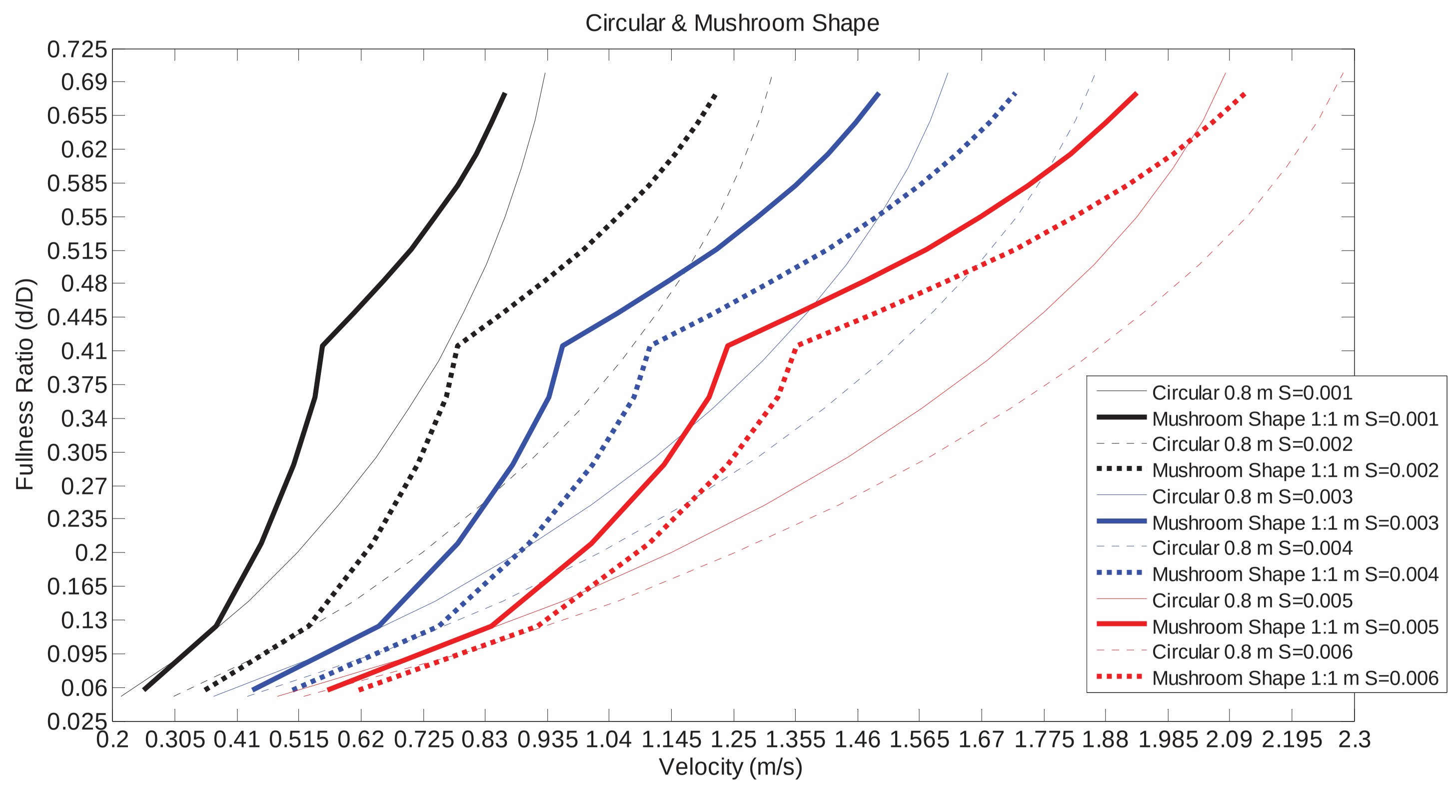


Figure 5.20.b Relation between fullness ratio and velocity in circular pipe of 0.8m Dia. and mushroom shape section 1m: 1m applied on slopes from 0.001 to 0.006.

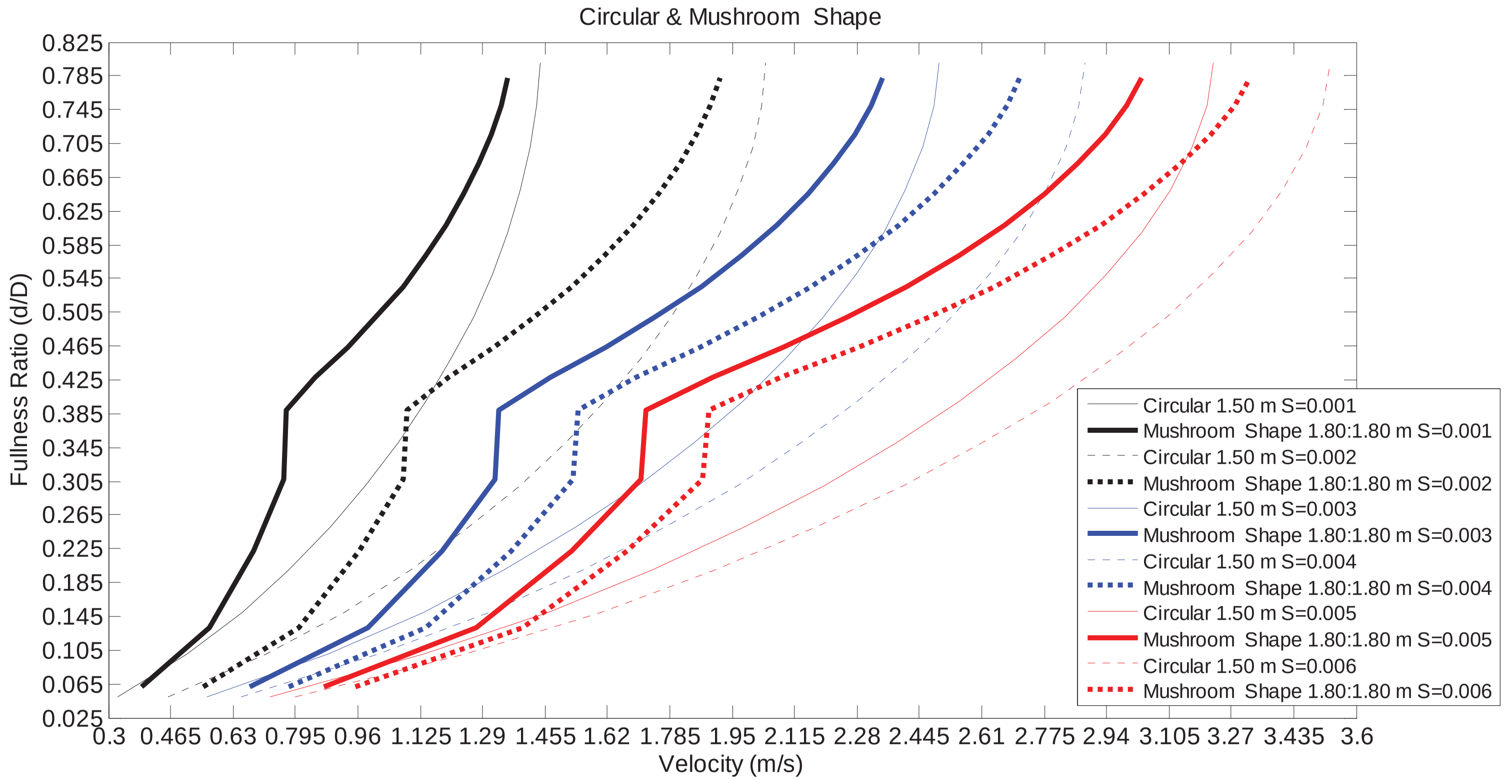


Figure 5.20.c Relation between fullness ratio and velocity in circular pipe of 1.5m Dia. and mushroom shape section 1.8m: 1.8m applied on slopes from 0.001 to 0.006.

5.6 Comparing the Flow Velocity among Circular, Vase, and Mushroom Shapes for the Same Diameter/Dimension and Same Slope (0.001)

As explained previously in Chapter 3, some sectors claim to improve the discharge velocities of low flows with about 30% through modifying the circular pipe by lining it from the inside with a different section (MSCIPP: Modifying Sectional Cured in Place Pipe), which is named by the writer as a mushroom section. The tests were performed by modifying a circular pipe (40 cm) in diameter into another shape likes Vase or Mushroom shape. These sectors used Manning formula throughout their calculations.

It seemed worth checking the real degree and range of improvement on the velocity after such modification. Therefore, calculations were performed on the three sections of circular, vase, and mushroom using the very same discharge flow values with the same step of increments. Obviously, the comparison cannot be realistic unless the same circular diameter is applied for the rest of the sections. This is because the improvement is claimed to function after lining from the inside of the circular pipe. In fact, the calculations ignored the thickness of the lining, just as the claiming sectors do in their claim.

The test of the improvement of the velocity was performed with the consideration of two alternative linings. The first is the vase and the other is the mushroom section. Both were compared with the circular following the same radius. The velocity versus discharge was observed for the three sections, following the same slope for S = 0.001as shown in Figure 5.21. The slope was intentionally selected to be very gentle on one hand to make the comparison realistic for the case when low velocities may be lower than the minimum allowed limits, and on the other hand, to make the slope matches the one claimed to be experimented by those sectors.

In Figure 5.21, where the circular curve is taken as a reference for comparison, the vase section showed the relatively best performance regarding increasing the velocity for relatively low flows. The mushroom section showed a slightly better performance for a narrow range of low flows. Both the vase and mushroom sections show lower velocities, when compared with the circular pipe, for high discharges.

However, in relevance to the latter behavior, the mushroom section showed significantly lower velocities for large flows in comparison with the vase one.

As a general conclusion for this numerical experiment, among the two attempted lining sections, the vase seems to be a winner. However, the overall improvement in velocity for low discharges does not appear to be even close to the claimed 30% for overall range of discharge. The calculations show that this improvement is of merely 0.04 m/s in the best range of improvement. This resulted, as could be seen in the Figure 5.21, from dividing the velocity of the point of intersection between the vase and mushroom curves, where the improvement of the velocity appears to be at its best, by the velocity of the circular pipe for the same discharge. This value is measured to be of 0.22m/s for the intersection point and 0.18m/s for the circular section. The ratio between both values is 1.22, which means 22% improvement. It is not true to claim that the overall improvement of velocity is 30% because all the rest of range of discharge values show lower than this ratio. Moreover, the velocity of the vase section (which is relatively even better than the mushroom's) goes even lower than that of the circular pipe.

The general conclusion indicates the inaccuracy of the claimed 30% ratio, which is far higher than those obtained through calculation in this research. In fact, an increase on the velocity with of 4 cm/s over the existing 18cm/s may not worth all the cost and trouble involved in the lining process recommended by some sectors.

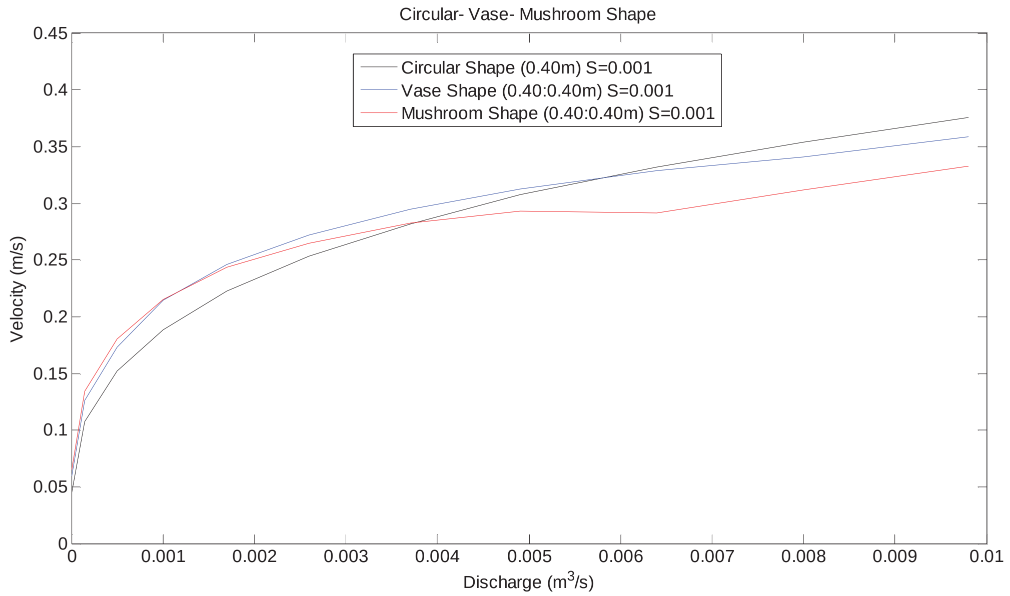


Figure 5.21 Relation between velocity and discharge in circular, vase, and mushroom shapes for slope S= 0.001.

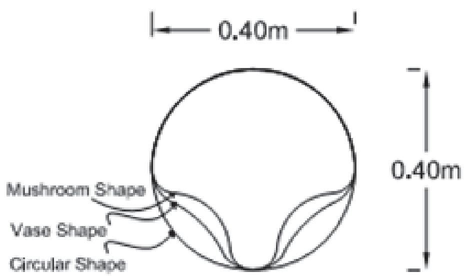


Figure 5.22 Represents a circular cross section pipe in comparison with two modified cross sections both vase and mushroom shapes.

5.7 Comments

The investigated non-circular group of all chosen sizes for all slopes, showed slightly higher velocity for low discharges in comparison with circular one. This is observed particularly when fullness ratio ranges between 0.05 and 0.25%. However, when the fullness ratio is above that range, the velocity appears to be relatively higher in circular section.

During investigating and making numerical calculations among non- circular pipes in comparison with the circular one, it is observed that, for low discharges, the egg shape form (2:3) has a relatively longer range of higher velocity ratio (V_e/V_c) than all other non-circular shapes (Kite, Vase, and Mushroom Shape).

With the consideration that the relatively high cost of construction of egg-shaped pipes along with the cost of both manufacturing and embedding/layout of the pipe in its proposed location (due to its being horizontally non-symmetric), the advantage of having a slightly higher velocity for low flows over the circular cross section is questionable.

It worth indicating that despite the egg-shaped having the advantage of a relatively higher velocity for low flows, it also has the slightly good other advantage, when selected to serve the same flow, of having a relatively smaller radius for the top section, which should be relatively more resistant to the upper soil pressure. However, the accompanied disadvantage explained in the previous paragraph should not be ignored, and accordingly the decision should be based on the regional balance between the advantages and disadvantages.

Whereas some studies (mentioned in chapter four) claimed that the Egg-shaped has higher velocity as much as 30% in comparison with circular shape, obviously, the calculations previously explained in chapter four were performed without specific and/or realistic comparison neither regarding the following variables:

a- The selection of the diameter/dimension of pipe.
b- The equality of the discharge in all attempts
c- The lack of clear standard conditions regarding the fullness ratio in pipes, and its being safe against any unexpected waves/fluctuation in the flow.
d- The similarity between the total pipes cross sectional areas, taken for comparison, which could fit the design discharge.

Since the main objective is to identify the optimum pipe cross section among circular and non circular ones for the same design discharge, it is essential to take into consideration all the design aspects during the comparison stage. Only then, the final decision could be made with the consideration of the local cost regarding the non-circular pipes.

CHAPTER 6

EVALUATION OF COMPUTER PROGRAMS FOR SEWER SYSTEM DESIGN

In this research, one of the important topics to be investigated is the applicability of computer programs for the design of sewer systems. For this purpose, “SEWERCAD and MSKANAL” have been selected which are considered powerful programs for the design and analysis of gravity flow, pressure flow through pipe networks, and pumping station. The main objective in this chapter is basically to present a brief description of the use of the programs, and also, to identify the applicability and feasibility of each of these two programs in developing countries.

6.1 SewerCAD Program

6.1.1 SewerCAD Details

The program “SewerCAD” can be run in AutoCAD mode giving all the power of AutoCAD’s capabilities, or in Stand-Alone mode utilizing our own graphical interface. SewerCAD allows you to construct a graphical representation of a pipe network containing information such as pipe data, pump data, loading, and infiltration. You have a choice of conveyance elements including circular pipe, arches, boxes and more. The gravity network is calculated using the built-in numerical model, which utilize both the direct step and standard step gradually varied flow methods. Flow calculations are valid for both surcharged and varied flow situations, including hydraulic jump, back water, and drawdown curves [55]

6.1.1.1 SewerCAD Main Windows

Both the SewerCAD Stand-Alone interface and AutoCAD interface have many components common to windows based program. The following figures (6.1a and

6.1b) illustrate some of the important areas that make up the SewerCAD stand-Alone and AutoCAD windows, respectively. Notice that many of the windows components, such as menus and toolbars, are very similar for the Stand-Alone editor and AutoCAD. Other features, such as the command line, are only available in AutoCAD [55].

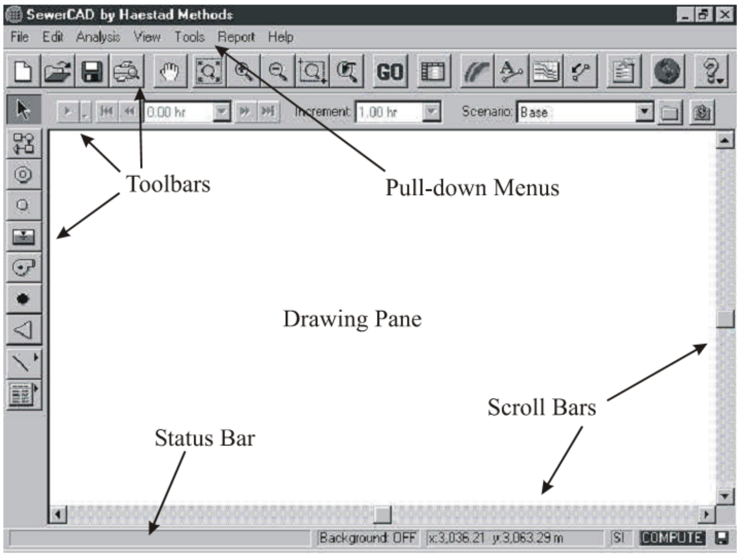


Figure 6.1.a SewerCAD stand-alone interface [55].

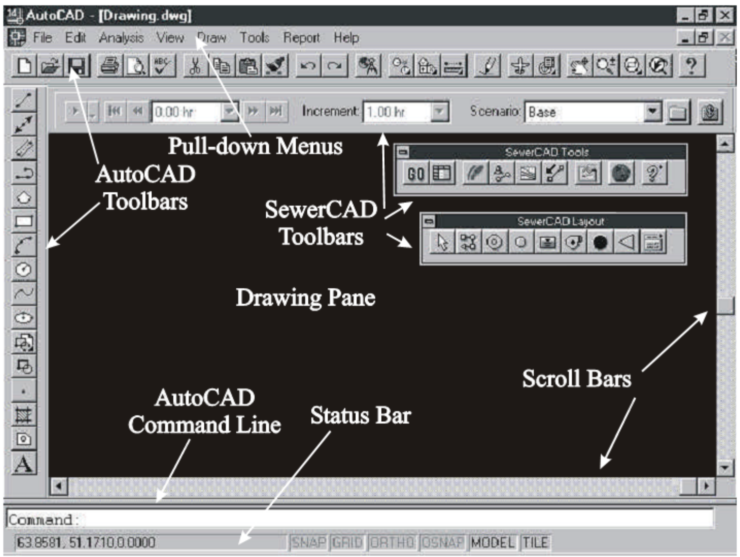


Figure 6.1.b SewerCAD AutoCAD interface [55].

6.1.1.2 Entering Data for Gravity Pipe System

After drawing the proposed sewer pipe layout lines and define the number and location of manholes, each element, such as; Manhole (MH), Pipe Line (P), and Outlet (O) should to be selected, then, double -click the element to bring up the editor. Figure 6.2 shows the layout of a typical manhole (MH), gravity pipe Line (P), and outlet (O).

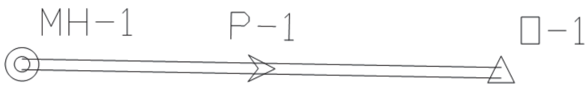


Figure 6.2 Layout of Manhole (MH), Pipe Line (P), and Outlet (O).

A. Manhole (MH)

Click the element "MH" double-clicks with the selection tool to open the element's editor, and select the general Tab to enter manhole's data including ground elevation, rim (street surface: surface of manhole) elevation, and sump (bottom) elevation. Then, select loading Tab to define unit sanitary load (dry weather load: for only sanitary flow) as outlined in the Manhole data table shown in Figure 6.3.a [55].

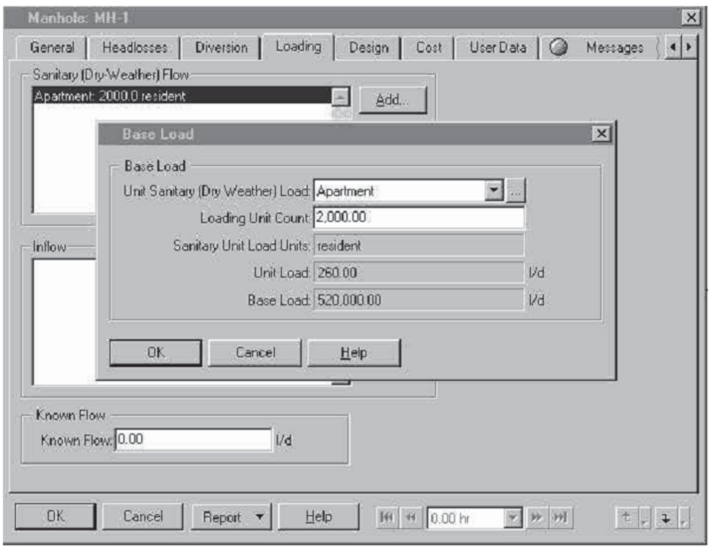


Figure 6.3.a Manhole data table in SewerCAD program [55].

B. Gravity Pipe Line (P)

Click the element "P" double-clicks with the selection tool to open the element's editor, and select the general Tab to select pipe section, pipe material, manning coefficient (in case of having Manning formula), section size, and number of sections, then, enter upstream and downstream invert elevation as outlined in the gravity pipe data Table shown in Figure 6.3.b.

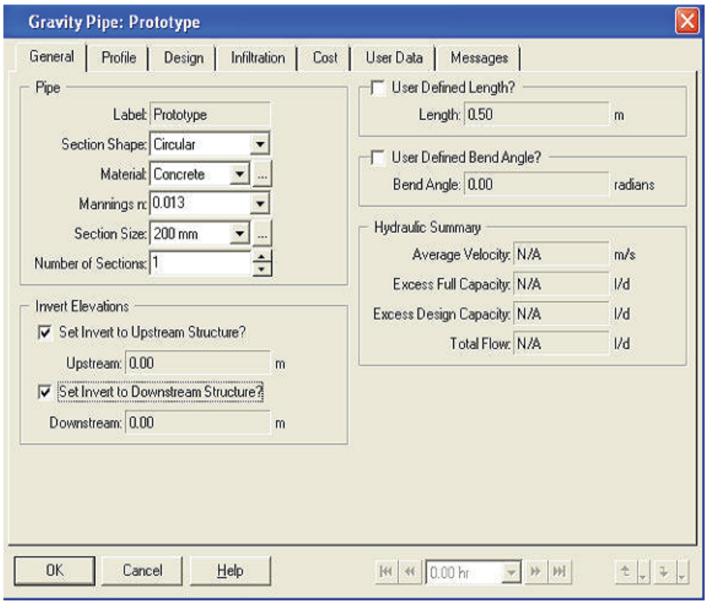


Figure 6.3.b Gravity pipe data table in SewerCAD program [56].

C. Outlet (O)

Click the element 'O', double-clicks with the selection tool to open the element's editor, and select the general tab to enter manhole's data including ground elevation, rim elevation, and sump elevation as outlined in the outlet data Table shown in Figure 6.3.c [55].

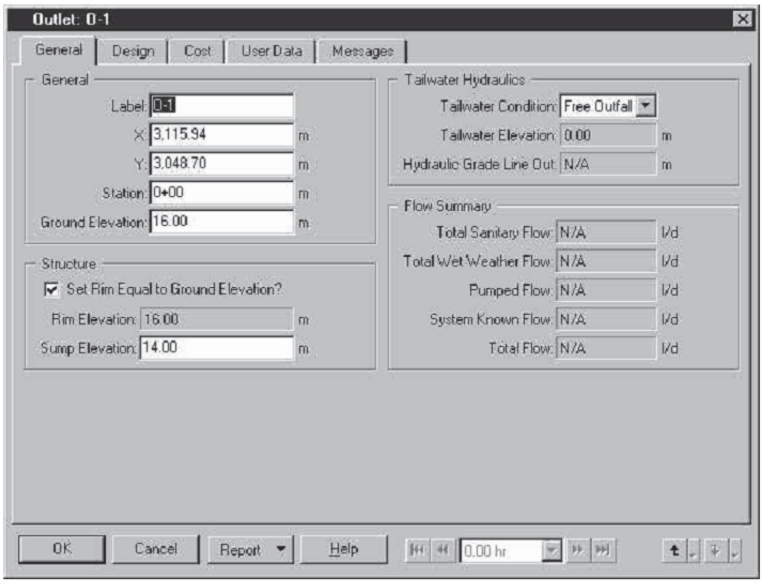


Figure 6.3.c Outlet data table in SewerCAD program [55].

6.1.1.3 Analysis of the Program

Click the GO button in SewerCAD main window to bring up the calculation dialog, and then, click Go button on the dialog to analyze the model. When calculations are completed, a Results report would be displayed as shown in Figure 6.4 [55].

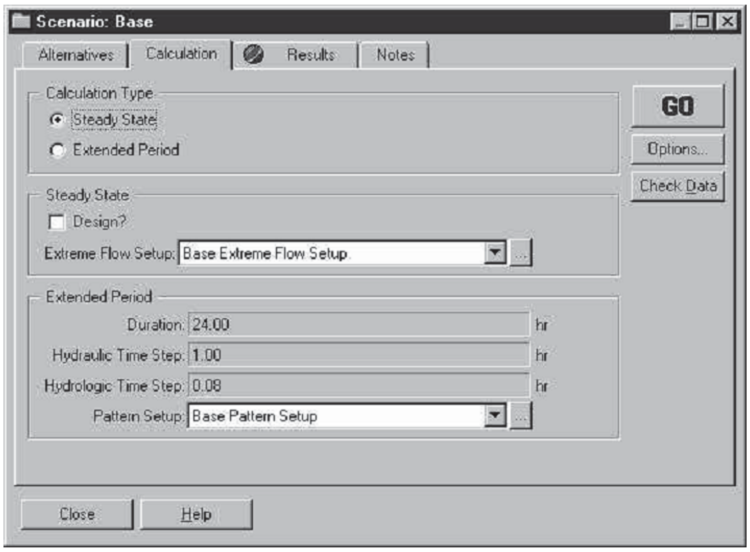


Figure 6.4 Shows the calculation tab in SewerCAD program [55].

Notice the light displayed on the Result Tab of the dialog. It could be observed quickly if there were warnings or a failure with a glance at the light. A green light indicates no warnings or failure; a yellow light indicates warnings, while a red light indicates problems. Figure 6.5 indicates the warning element calculation message [55].

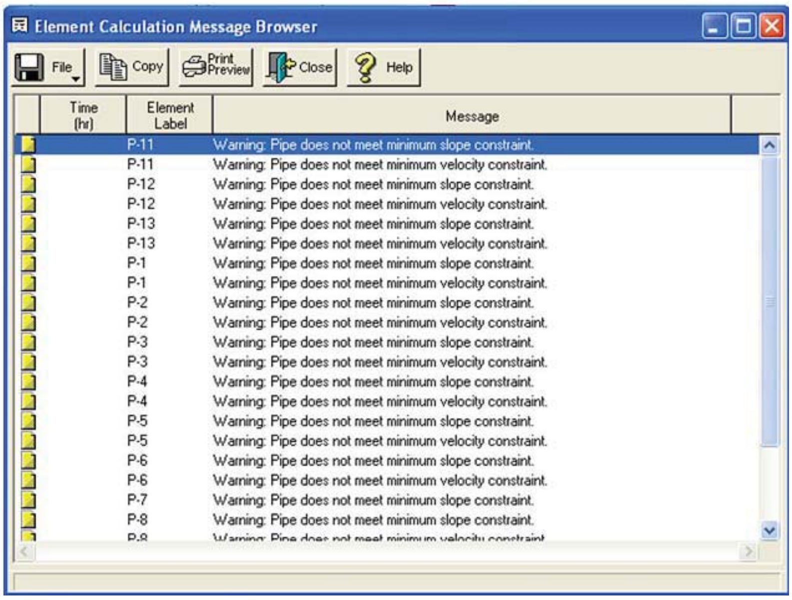


Figure 6.5 Indicates the warning element calculation message in SewerCAD program [56].

6.1.2 Design Example (Using SewerCAD)

The design example is an implemented project of sanitary sewer system in Gaziantep - Turkiye, which is a residential area nearby the city center of Gaziantep, named “Gazi-Mahallesi”. This region is shown in Figure 6.6. The project has been executed more than 13 years ago, and the whole system is designed to flow by gravity.

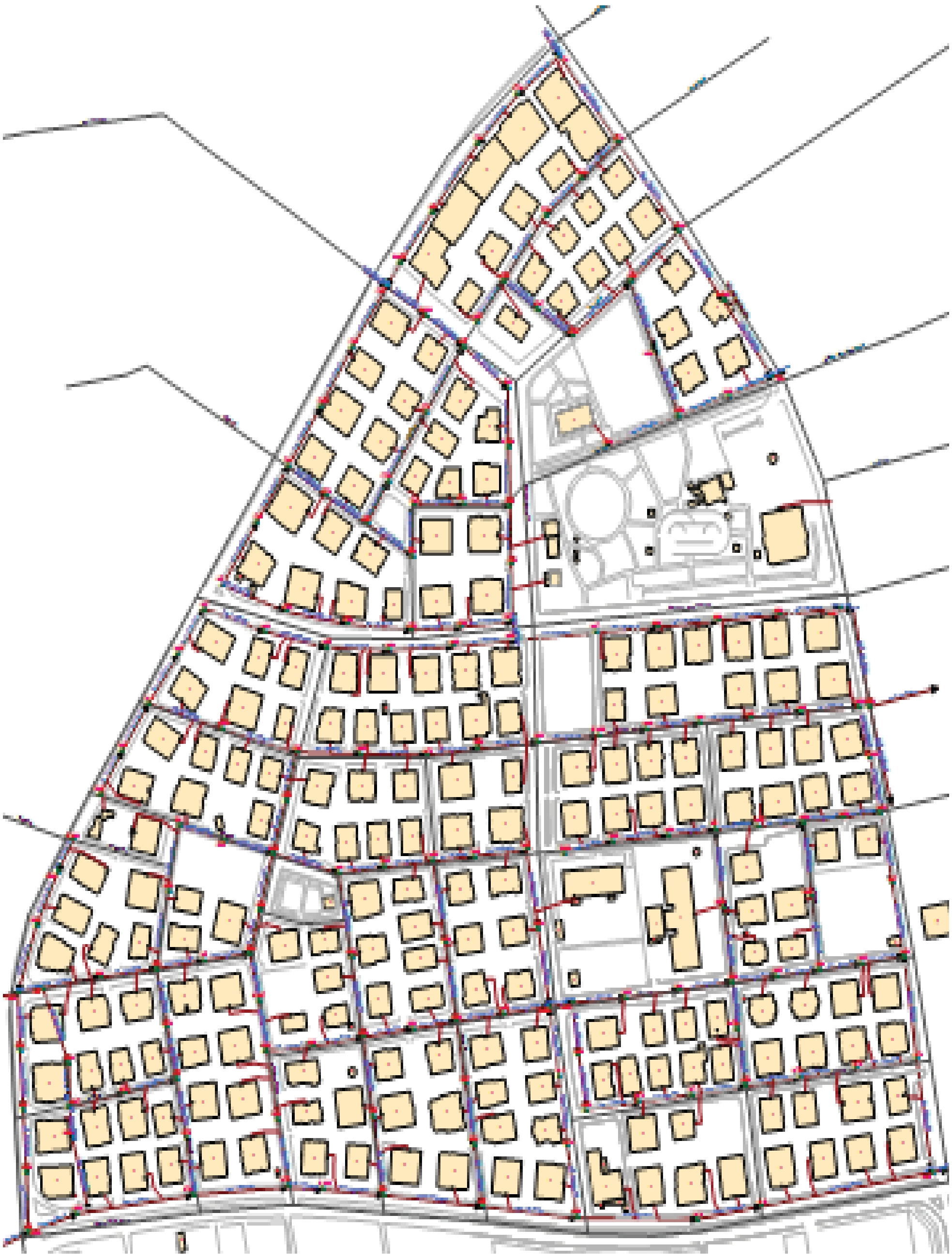


Figure 6.6 Layouts Showing the block distribution and sanitary sewer system in 'Gazi- Mahallesi' in Gaziantep, Turkiye.

6.1.2.1 Project Constraints

The information explained below is obtained from Water Supply and Sewerage of Gaziantep (GASKİ):

A- The project plan shows a total of 206 housing blocks for multi-storey buildings, one primary school, one Mosque, one basketball court, one restaurant, and one public garden (including tea and coffee shop).

B- The total project area is about 60 hectares.

C- The predicted life length of the project is estimated to be 30 years.

D- The predicted population for 60 hectare is taken to be 25000 capita for 30 years.

6.1.2.2 Design Limitations

A- The daily water consumption per capita in Gaziantep is estimated to be 200 l/day/capita. This same amount is considered to flow within 12 hours in sewer systems.

B- For the existing school shown in Figure 6.6, which has an area of (2792.5m^2), quantity of sewage discharge, could be designed with the consideration of the following two assumptions:

I- Firstly, by assuming number of toilets and hand washing basin for the whole school, which may estimated to be 60 l/s.

II- Secondly, by assuming 800 students each may consumes 50 l/day. Accordingly, the total discharge would be 0.925 l/s which are very little in comparison with the first case, for this purpose, an average quantity of 20 l/s/capita has been taken for the whole school population.

C- In relevance to the other existing service units, such as mosque, restaurant, tea café, and coffee shop shown in Figure 6.6 are listed below:

Table 6.1 Predicted Populations in Service Units

Name of units	Area (m^2)	Population
Basketball Court	420	100 Players
Restaurant*	615	50 Customers
Tea Café	240	50 Customers
Coffee Shop	300	50 Customers
Mosque	1120	100 Prayer

* During holy months or days, total number of customers may exceed 200 persons, but in normal days, it may not exceed 50 customers by the fact that the disposed discharges are from toilets, kitchens and hand washing basin only. For the design purpose, the total number of customers has been predicting to be 50 persons consuming 200 l/day (the maximum probable consumption).

6.1.2. 3 Hydraulic Limitations

According to Municipality of Gaziantep- Akkent Housing Estate/ Infrastructure Projects, the proposed hydraulic limitations are listed below:

Table 6.2 Hydraulic Elements for Sanitary Sewer System

Hydraulic Elements	Units	Minimum Value	Maximum Value
Average Velocity	m/s	0.3	3
Pipe Grade	m/m	0.001	0.03

In the design example, there are four sewer pipes entering the region in concern with different diameters (Φ300mm, Φ 400mm, Φ 800mm, and Φ 1200mm). The inflow of these pipes is shown in Figure 6.6. The discharge values shown in this figure were estimated because of the unavailability of the real flows.

Table 6.3 shows the allowable minimum and maximum discharge in the pipe regarding minimum and maximum pipe slope:

Table 6.3 Amount of Discharge in different Pipe diameter

Pipe Diameter (mm)	Minimum Slope (1/s)	Maximum Slope (1/s)	Fullness Ratio %	Amount of Discharge for Minimum Slope (l/s)	Amount of Discharge for Maximum Slope (l/s)
Φ 300	500	7	50	53.7	380
Φ 400	600	15	60	106.3	565
Φ 800	1200	50	90	476.5	1976
Φ 1200	2000	75	90	1074.4	4713.2

In the design example, minimum amount of discharge has been taken as a first design trail to check whether the system is within the design limits or not.

According to Municipality of Gaziantep- Akkent Housing Estate/ Infrastructure Projects:

I- The allowable minimum depth of cover has been taken from (1.2-1.7) m for starting points.

II- The allowable minimum and maximum drop points in manholes taken as (0.75-4) m respectively.

6.1.3 Program Results

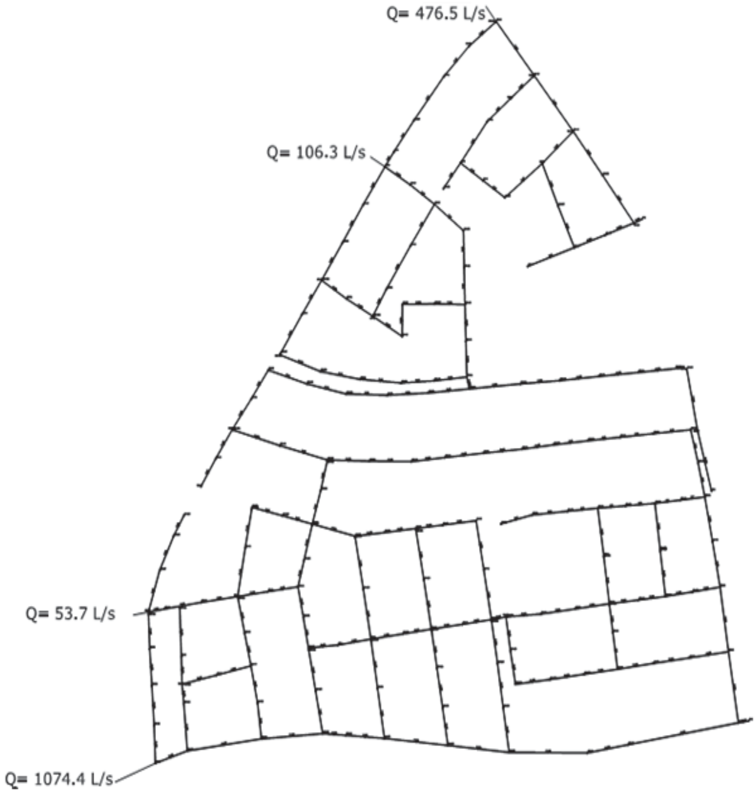


Figure 6.7 The designed outlines of the sanitary sewer system for Gazi-Mahalle project using SewerCAD program.

After running the program, an element calculation message gave warning that indicate two types of errors, which constitutes about (32.5%) of the whole project, the first warning is that the allowable velocity falls below the minimum allowed value due to the pipes being laid on gentle slope. The second one indicates that the design discharge is above the allowed pipe discharge limits. The latter warning could be explained by the fact that the real discharge is above the maximum allowed limits, and also, the slope of most pipes is too gentle. Therefore, the results appear to be in the form of three groups: (a) pipes without errors, (b) pipes with less than minimum allowable velocity, and (c) pipes that over flooded.

The listed reports and profiles are typical example of previously explained the three groups:

A. Successfully Designed Pipes

The listed report in Figure 6.8 and profile in Figure 6.9 are the result of one of the pipes that successfully designed without error messages.

Detailed Report for Gravity Pipe: P-363

Scenario Summary	
Scenario	Base
Physical Properties Alternative	Base-Physical Properties
Sanitary (Dry Weather) Loading	Base-Sanitary (Dry Weather) Loading
Infiltration and Inflow Loading	Base-Infiltration and Inflow Loading
Known Flow Loading Alternative	Base-Known Flow
Structure Headlosses Alternative	Base-Structure Headlosses
Boundary Conditions Alternative	Base-Boundary Conditions
Design Constraints Alternative	Base-Design Constraints
Initial Settings Alternative	Base-Initial Settings
Operational Alternative	Base-Operational
Capital Cost Alternative	Base-Capital Cost
User Data Alternative	Base-User Data

Pipe Characteristics				
Upstream Node	MH-349		Number of Sections	1
Downstream Node	MH-27		Section Shape	Circular
Bend Angle	7.92	degrees	Section Size	200mm
Length	39.929	m	Material	Concrete
Constructed Slope	0.036816	m/m	Mannings n	0.013

Hydraulic Summary					
Total Flow	0.763600	l/s	Profile Description	Composite S1 S2	
Full Capacity	62.931611	l/s	Gravity Element Headloss	1.454	m
Excess Full Capacity	62.168011	l/s	Velocity In	0.390	m/s
Design Capacity	21.207183	l/s	Velocity Out	0.181	m/s
Excess Design Capacity	20.443583	l/s	Average Velocity	0.683	m/s

Elevations/Depths

	Invert (m)	Ground (m)	Crown (m)	Cover (m)	Depth (m)	Hydraulic Grade (m)	EGL (m)
Upstream	49.600	51.600	49.800	1.800	0.023	849.623	49.630
Downstream	48.130	50.000	48.330	1.670	0.038	848.168	48.170

Figure 6.8 Detailed report for gravity pipe: P-363.

Detailed Report for Gravity Pipe: P-363

Pipe Design Options			
Design Pipe?	true	Design Upstream Invert?	true
Design Downstream Invert?	true	Specify Local Pipe Constraints	true
Part Full Design?	true	Design Percent Full	40.0 %
Allow Multiple Sections?	false	Maximum Number Sections	N/A
Limit Section Size?	false	Maximum Section Rise	N/A m

Pipe Design Constraints			
Minimum Velocity	0.300 m/s	Maximum Velocity	3.000 m/s
Minimum Cover	1.200 m	Maximum Cover	4.572 m
Minimum Slope	0.001000 m/m	Maximum Slope	0.050000 m/m

Local Infiltration			
Local Infiltration	0.000000 l/s	Local Additional Infiltration	0.000000 l/s
Local Total Infiltration	0.000000 l/s		

System Infiltration			
System Infiltration	0.000000 l/s	System Additional Infiltration	0.000000 l/s
System Total Infiltration	0.000000 l/s		

User Data			
Date Installed		Lining	
Existing	false	Condition	

Figure 6.8 Detailed report for gravity pipe: P-363. (Continued)

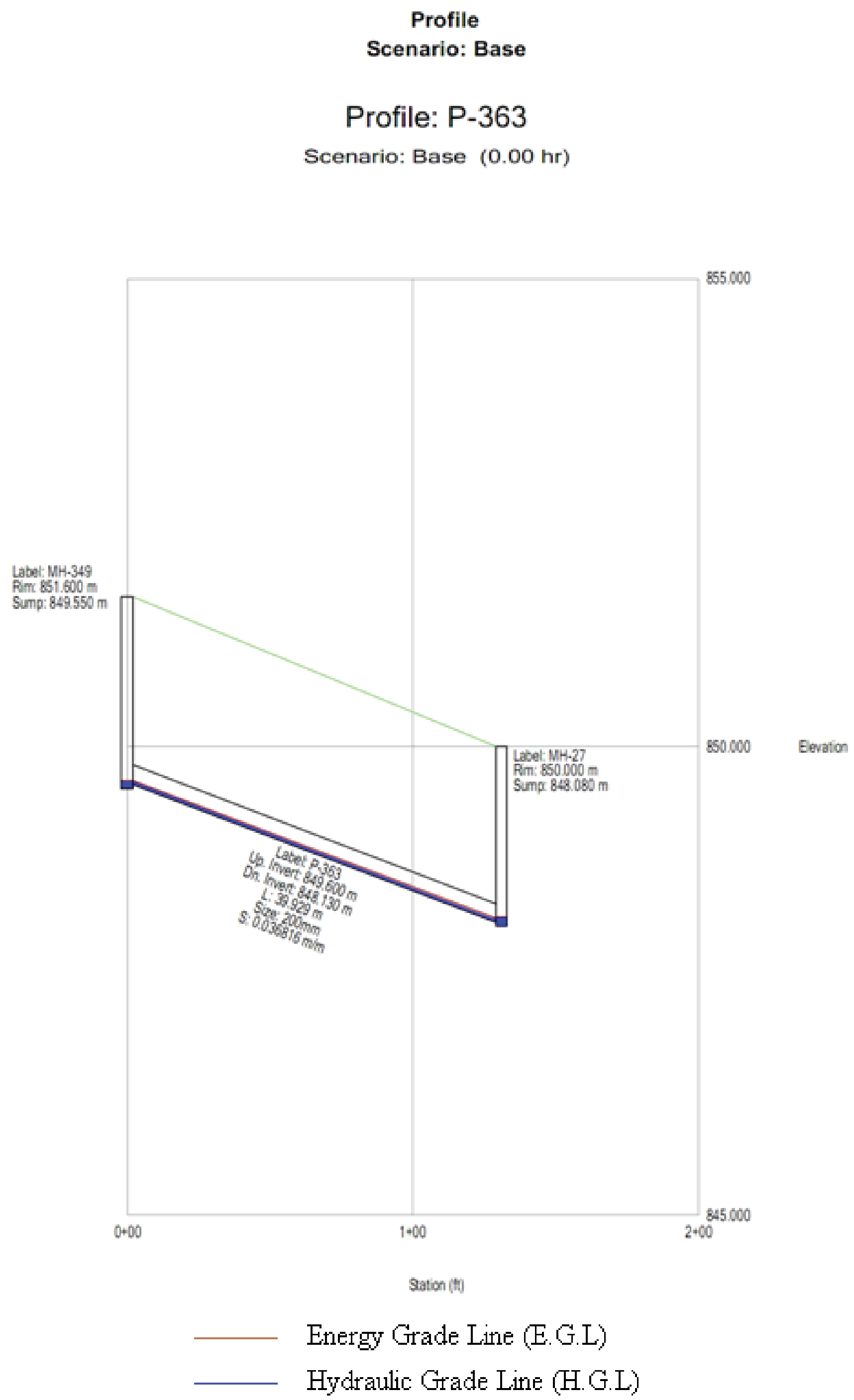


Figure 6.9 Indicates longitudinal cross-section of pipe No. 363 in SewerCAD program.

B. Warning Messages Relevant to Some Pipes

These pipes either do not meet the minimum allowable velocity, or, their design discharge is above pipe discharge. Figure 7.10 lists all the pipes that have warning element calculation message.

Scenario: Base
Element Calculation Message Browser

	Time (hr)	Element Label	Message
		P-138	Warning: Pipe does not meet minimum velocity constraint.
		P-441	Warning: Pipe does not meet minimum velocity constraint.
		P-140	Warning: Pipe discharge is above full flow capacity.
		P-140	Warning: Pipe discharge is above design capacity.
		P-442	Warning: Pipe does not meet minimum velocity constraint.
		P-444	Warning: Pipe discharge is above design capacity.
		P-6	Warning: Pipe discharge is above design capacity.
		P-446	Warning: Pipe does not meet minimum velocity constraint.
		P-447	Warning: Pipe discharge is above full flow capacity.
		P-447	Warning: Pipe discharge is above design capacity.
		P-15	Warning: Pipe discharge is above design capacity.
		P-27	Warning: Pipe does not meet minimum velocity constraint.
		P-451	Warning: Pipe does not meet minimum velocity constraint.
		P-111	Warning: Pipe discharge is above design capacity.
		P-452	Warning: Pipe does not meet minimum velocity constraint.
		P-453	Warning: Pipe does not meet minimum velocity constraint.
		P-454	Warning: Pipe does not meet minimum velocity constraint.
		P-455	Warning: Pipe does not meet minimum velocity constraint.
		P-7	Warning: Pipe discharge is above design capacity.
		P-456	Warning: Pipe discharge is above full flow capacity.
		P-456	Warning: Pipe discharge is above design capacity.
		P-457	Warning: Pipe discharge is above full flow capacity.
		P-457	Warning: Pipe discharge is above design capacity.
		P-8	Warning: Pipe discharge is above design capacity.
		P-461	Warning: Pipe does not meet minimum velocity constraint.
		P-462	Warning: Pipe does not meet minimum velocity constraint.
		P-108	Warning: Pipe discharge is above design capacity.
		P-139	Warning: Pipe discharge is above full flow capacity.
		P-139	Warning: Pipe discharge is above design capacity.
		P-370	Warning: Pipe discharge is above design capacity.
		P-371	Warning: Pipe discharge is above design capacity.
		P-372	Warning: Pipe discharge is above design capacity.
		P-168	Warning: Pipe does not meet minimum velocity constraint.
		P-467	Warning: Pipe does not meet minimum velocity constraint.
		P-468	Warning: Pipe does not meet minimum velocity constraint.
		P-470	Warning: Pipe does not meet minimum velocity constraint.
		P-178	Warning: Pipe discharge is above design capacity.

Figure 6.10 Element calculation message browsers.

Scenario: Base
Element Calculation Message Browser

	Time (hr)	Element Label	Message
		P-376	Warning: Pipe does not meet minimum velocity constraint.
		P-9	Warning: Pipe discharge is above design capacity.
		P-13	Warning: Pipe discharge is above design capacity.
		P-471	Warning: Pipe does not meet minimum velocity constraint.
		P-387	Warning: Pipe discharge is above full flow capacity.
		P-395	Warning: Pipe does not meet maximum slope constraint.
		P-395	Warning: Pipe does not meet maximum velocity constraint.
		P-159	Warning: Pipe discharge is above design capacity.
		P-177	Warning: Pipe discharge is above design capacity.
		P-17	Warning: Pipe discharge is above design capacity.
		P-109	Warning: Pipe discharge is above full flow capacity.
		P-109	Warning: Pipe discharge is above design capacity.
		P-179	Warning: Pipe does not meet minimum velocity constraint.
		P-179	Warning: Pipe discharge is above design capacity.
		P-406	Warning: Pipe discharge is above design capacity.
		P-407	Warning: Pipe discharge is above full flow capacity.
		P-407	Warning: Pipe discharge is above design capacity.
		P-411	Warning: Pipe discharge is above design capacity.
		P-115	Warning: Pipe discharge is above full flow capacity.
		P-115	Warning: Pipe discharge is above design capacity.
		P-16	Warning: Pipe discharge is above design capacity.
		P-14	Warning: Pipe discharge is above design capacity.
		P-18	Warning: Pipe discharge is above design capacity.
		P-419	Warning: Pipe does not meet minimum velocity constraint.
		P-420	Warning: Pipe discharge is above full flow capacity.
		P-420	Warning: Pipe discharge is above design capacity.
		P-421	Warning: Pipe discharge is above full flow capacity.
		P-421	Warning: Pipe discharge is above design capacity.
		P-422	Warning: Pipe discharge is above design capacity.
		P-423	Warning: Pipe discharge is above full flow capacity.
		P-423	Warning: Pipe discharge is above design capacity.
		P-424	Warning: Pipe discharge is above full flow capacity.
		P-424	Warning: Pipe discharge is above design capacity.
		P-170	Warning: Pipe discharge is above design capacity.
		P-425	Warning: Pipe discharge is above full flow capacity.
		P-425	Warning: Pipe discharge is above design capacity.
		P-426	Warning: Pipe discharge is above full flow capacity.
		P-426	Warning: Pipe discharge is above design capacity.
		P-146	Warning: Pipe discharge is above full flow capacity.
		P-146	Warning: Pipe discharge is above design capacity.
		P-147	Warning: Pipe discharge is above full flow capacity.
		P-147	Warning: Pipe discharge is above design capacity.
		P-429	Warning: Pipe does not meet minimum velocity constraint.
		P-1	Warning: Pipe does not meet minimum velocity constraint.
		P-144	Warning: Pipe discharge is above design capacity.
		P-433	Warning: Pipe does not meet minimum velocity constraint.
		P-434	Warning: Pipe does not meet minimum velocity constraint.

Figure 6.10 Element calculation message browsers. (Continued)

The following reports and profiles in Figures 6.11, and 6.12 indicate pipes that have velocities below the minimum allowable limit, while Figures 6.13 and 6.14 indicate flooded pipes.

Detailed Report for Gravity Pipe: P-376

Scenario Summary	
Scenario	Base
Physical Properties Alternative	Base-Physical Properties
Sanitary (Dry Weather) Loading	Base-Sanitary (Dry Weather) Loading
Infiltration and Inflow Loading	Base-Infiltration and Inflow Loading
Known Flow Loading Alternative	Base-Known Flow
Structure Headlosses Alternative	Base-Structure Headlosses
Boundary Conditions Alternative	Base-Boundary Conditions
Design Constraints Alternative	Base-Design Constraints
Initial Settings Alternative	Base-Initial Settings
Operational Alternative	Base-Operational
Capital Cost Alternative	Base-Capital Cost
User Data Alternative	Base-User Data

Pipe Characteristics					
Upstream Node	MH-115		Number of Sections	1	
Downstream Node	MH-67		Section Shape	Circular	
Bend Angle	1.45	degrees	Section Size	200mm	
Length	46.939	m	Material	Concrete	
Constructed Slope	0.003409	m/m	Mannings n	0.013	

Hydraulic Summary					
Total Flow	0.654500	l/s	Profile Description	M1	
Full Capacity	19.148972	l/s	Gravity Element Headloss	0.154	m
Excess Full Capacity	18.494472	l/s	Velocity In	0.283	m/s
Design Capacity	6.452969	l/s	Velocity Out	0.211	m/s
Excess Design Capacity	5.798469	l/s	Average Velocity	0.283	m/s

Elevations/Depths

	Invert (m)	Ground (m)	Crown (m)	Cover (m)	Depth (m)	Hydraulic Grade (m)	EGL (m)
Upstream	48.300	50.400	48.500	1.900	0.025	848.325	48.329
Downstream	48.140	50.300	48.340	1.960	0.031	848.171	48.173

Figure 6.11 Detailed report for gravity pipe: P-376 that does not meet minimum allowable velocity.

Detailed Report for Gravity Pipe: P-376

Pipe Design Options			
Design Pipe?	true	Design Upstream Invert?	true
Design Downstream Invert?	true	Specify Local Pipe Constraints	true
Part Full Design?	true	Design Percent Full	40.0 %
Allow Multiple Sections?	false	Maximum Number Sections	N/A
Limit Section Size?	false	Maximum Section Rise	N/A m

Pipe Design Constraints			
Minimum Velocity	0.300 m/s	Maximum Velocity	3.000 m/s
Minimum Cover	1.200 m	Maximum Cover	4.572 m
Minimum Slope	0.001000 m/m	Maximum Slope	0.030000 m/m

Local Infiltration			
Local Infiltration	0.000000 l/s	Local Additional Infiltration	0.000000 l/s
Local Total Infiltration	0.000000 l/s		

System Infiltration			
System Infiltration	0.000000 l/s	System Additional Infiltration	0.000000 l/s
System Total Infiltration	0.000000 l/s		

User Data			
Date Installed		Lining	
Existing	false	Condition	

Message List

Time (hr)	Message
	Warning: Pipe does not meet minimum velocity

Figure 6.11 Detailed report for gravity pipe: P-376 that does not meet minimum allowable velocity. (Continued)

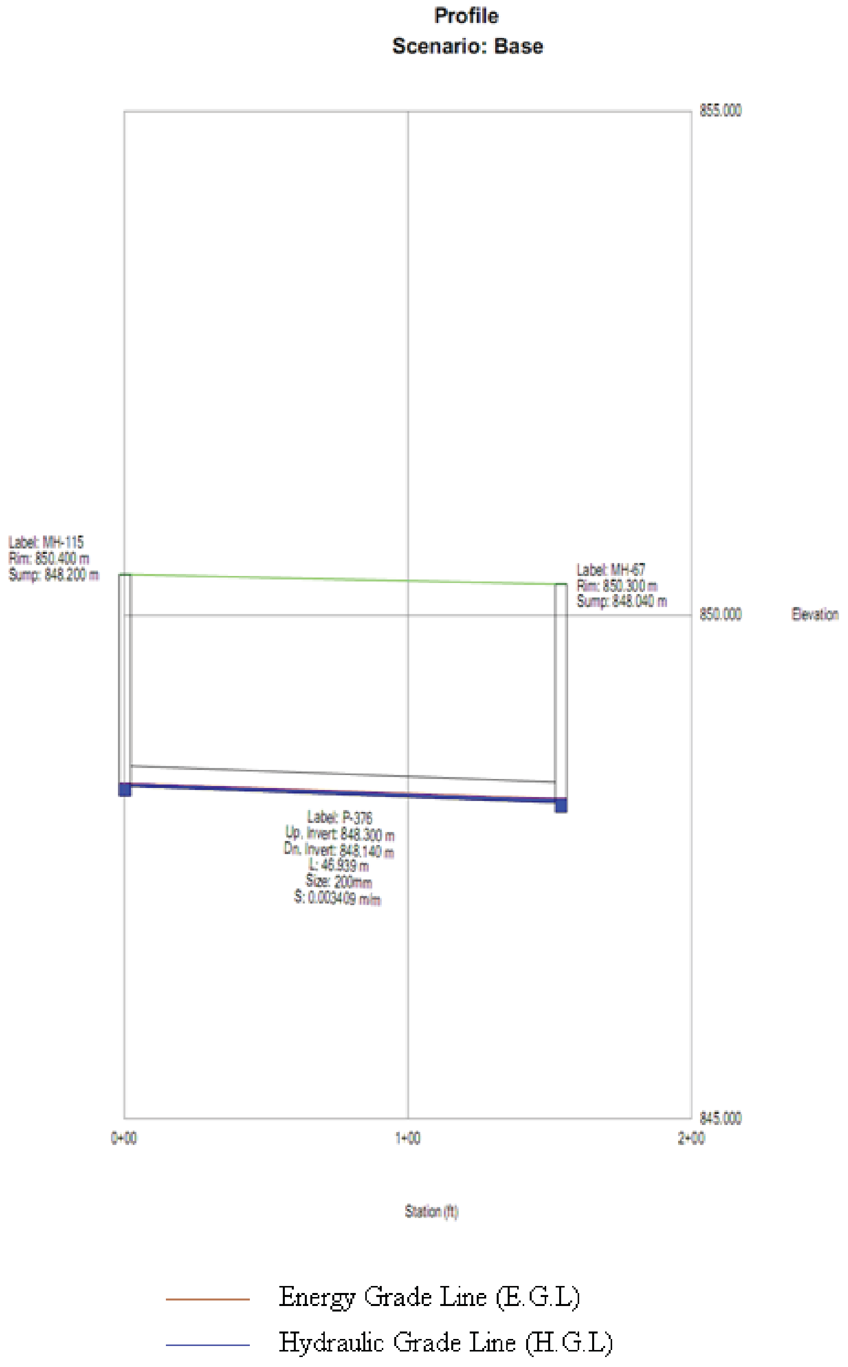


Figure 6.12 Indicates longitudinal cross-section of pipe No. 376 in SewerCAD program.

Detailed Report for Gravity Pipe: P-423

Scenario Summary	
Scenario	Base
Physical Properties Alternative	Base-Physical Properties
Sanitary (Dry Weather) Loading	Base-Sanitary (Dry Weather) Loading
Infiltration and Inflow Loading	Base-Infiltration and Inflow Loading
Known Flow Loading Alternative	Base-Known Flow
Structure Headlosses Alternative	Base-Structure Headlosses
Boundary Conditions Alternative	Base-Boundary Conditions
Design Constraints Alternative	Base-Design Constraints
Initial Settings Alternative	Base-Initial Settings
Operational Alternative	Base-Operational
Capital Cost Alternative	Base-Capital Cost
User Data Alternative	Base-User Data

Pipe Characteristics					
Upstream Node	MH-165		Number of Sections	1	
Downstream Node	MH-173		Section Shape	Circular	
Bend Angle	0.17	degrees	Section Size	300mm	
Length	42.062	m	Material	Concrete	
Constructed Slope	0.003566	m/m	Mannings n	0.013	

Hydraulic Summary					
Total Flow	89.315600	l/s	Profile Description	Pressure	
Full Capacity	57.746890	l/s	Gravity Element Headloss	0.359	m
Excess Full Capacity	-31.568710	l/s	Velocity In	1.264	m/s
Design Capacity	28.873445	l/s	Velocity Out	1.264	m/s
Excess Design Capacity	-60.442155	l/s	Average Velocity	1.264	m/s

Elevations/Depths

	Invert (m)	Ground (m)	Crown (m)	Cover (m)	Depth (m)	Hydraulic Grade (m)	EGL (m)
Upstream	45.590	48.000	45.890	2.110	0.562	846.152	46.234
Downstream	45.440	47.960	45.740	2.220	0.353	845.793	45.875

Figure 6.13 Detailed report for gravity pipe: P-423 that is above design discharge.

Detailed Report for Gravity Pipe: P-423

Pipe Design Options			
Design Pipe?	true	Design Upstream Invert?	true
Design Downstream Invert?	true	Specify Local Pipe Constraints	true
Part Full Design?	true	Design Percent Full	50.0 %
Allow Multiple Sections?	false	Maximum Number Sections	N/A
Limit Section Size?	false	Maximum Section Rise	N/A m

Pipe Design Constraints			
Minimum Velocity	0.300 m/s	Maximum Velocity	3.000 m/s
Minimum Cover	1.200 m	Maximum Cover	4.572 m
Minimum Slope	0.001000 m/m	Maximum Slope	0.030000 m/m

Local Infiltration			
Local Infiltration	0.000000 l/s	Local Additional Infiltration	0.000000 l/s
Local Total Infiltration	0.000000 l/s		

System Infiltration			
System Infiltration	0.000000 l/s	System Additional Infiltration	0.000000 l/s
System Total Infiltration	0.000000 l/s		

User Data			
Date Installed		Lining	
Existing	false	Condition	

Message List

Time (hr)	Message
	Warning: Pipe discharge is above full flow capacity
	Warning: Pipe discharge is above design capacity

Figure 6.13 Detailed report for gravity pipe: P-423 that is above design discharge. (Continued)

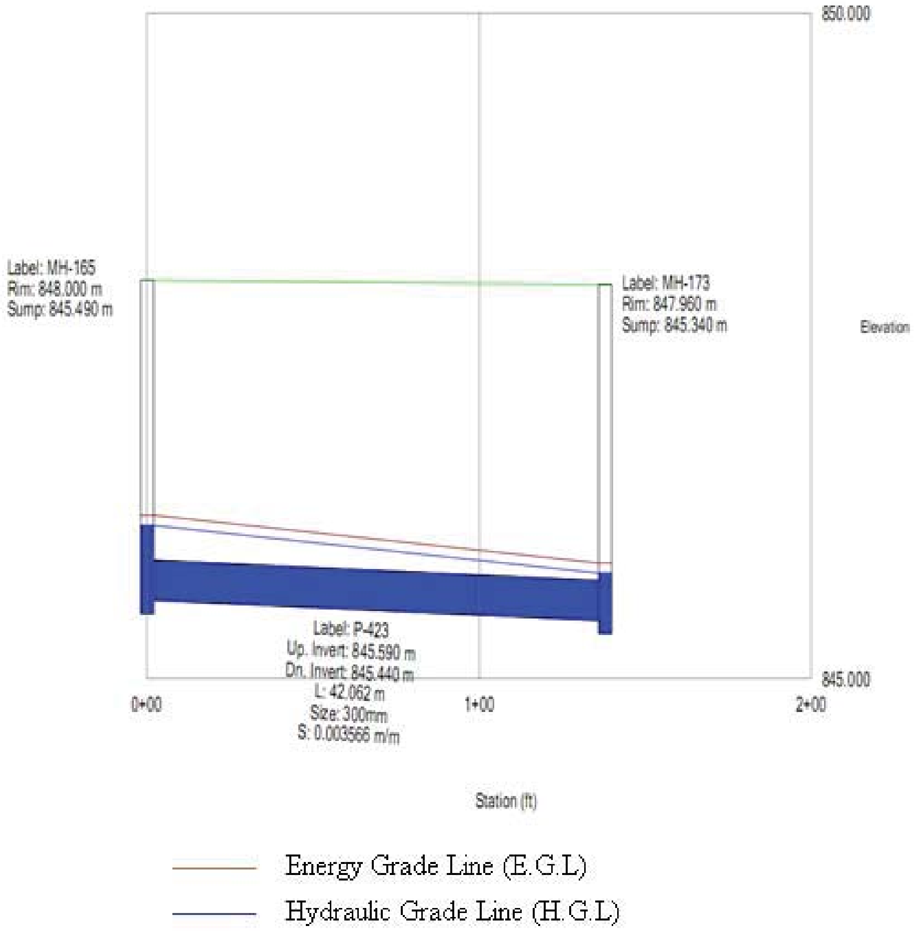


Figure 6.14 Indicates longitudinal cross-section of pipe No. 423 in SewerCAD program.

6.1.3 Analysis of the Error Messages

During the design stage, it appeared that most errors are caused due to having slopes below the minimum, which reduces the velocity of the discharge to a limit that is lower than the allowable one. The other type of errors is caused due to the discharge exceeding the design value, which results in certain flooding. These two reasons are likely to cause blockage and overflow to the system.

The investigations within the relevant region revealed that the main sewer lines shown in Figure 6.6, which have diameters of 800 and 1200 mm, have been executed and laid previously before the construction of project in Gazi-Mahalla, and consequently, the pipe lines had to be laid on a certain elevation. This resulted in being obliged to design the sewer lines of sewer system in Gazi-Mahalla system following the least slope in order to keep the system flowing by gravity.

Also, it is observed that program errors have appeared in spite of taking the design discharge as a minimum value for the four pipes entering the region in concern from the outside.

The pressure is likely to increase on the municipality to reconstruct the pipes that cannot convey the current discharge, and/or to modify the slope of those pipes that does not meet minimum allowable velocity limits.

6.2 MsKanal Program

MsKanal is a program prepared to assist the design of drainage and waste water as well as to make hydraulic modeling. This program seems to have been developed particularly to serve municipalities, utility authorities, infrastructure establishments, and civil and environmental engineers. MsKanal is developed by Turkish programmers and engineers according to local standards, international standards, and projects that run on 'Microstation Developed Language' [57].

6.2.1 MsKanal Details

Developed by the programming language of Microstation, MDL (Microstation Development Language), MsKanal can make advanced element drawings, calculations and design, modifications and database processes in a fast and flexible way with the strength of Microstation on graphic and non-graphic media. This software runs on versions of Microstation V8, XM, and 8i and can be upgraded for new versions [57].

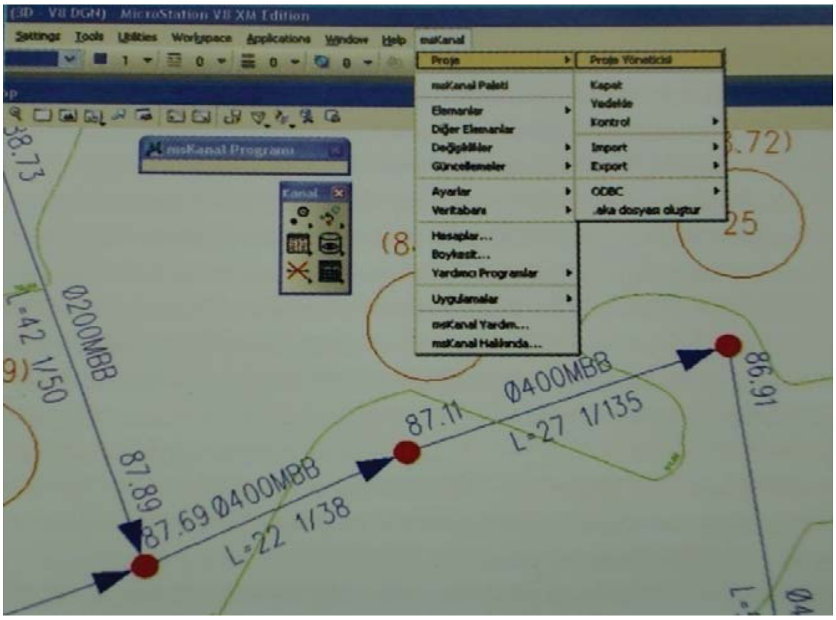


Figure 6.15 Microstation V8 and MsKanal main window [57].

6.2.1.1 DTM (Digital Terrain Model)-Optional

With the DTM property of MsKanal, there is no need for inputting ground elevation by interpolation on digital maps. If DTM of the region exists, Manhole ground elevation belonging to the manhole points will be input automatically in the model and written into the database as the database as the manhole are placed [57].

Figure 6.16 Manhole data table in MsKanal program [57].

6.2.1.2 Flexible Parameters and Settings

A- Project type can be selected depending on whether the planned system is wastewater or stormwater,

B- Manhole names can be linked to a contour map automatically,

C- Standard sized pipes with the required diameter and material and its properties can be defined in a pipe catalogue, only required ones can be taken into consideration while designing and different pipe catalogue can be created,

D- Setting can be applied for element placing and any change on these setting is possible during the element creation,

E- Properties of the element such as color, thickness, line style, layer and font can be defined and changed as desired,

F- Area types, which are used for wastewater and stormwater, can be defined, values like population density, water consumption and flow peak coefficient can be changed. [57]

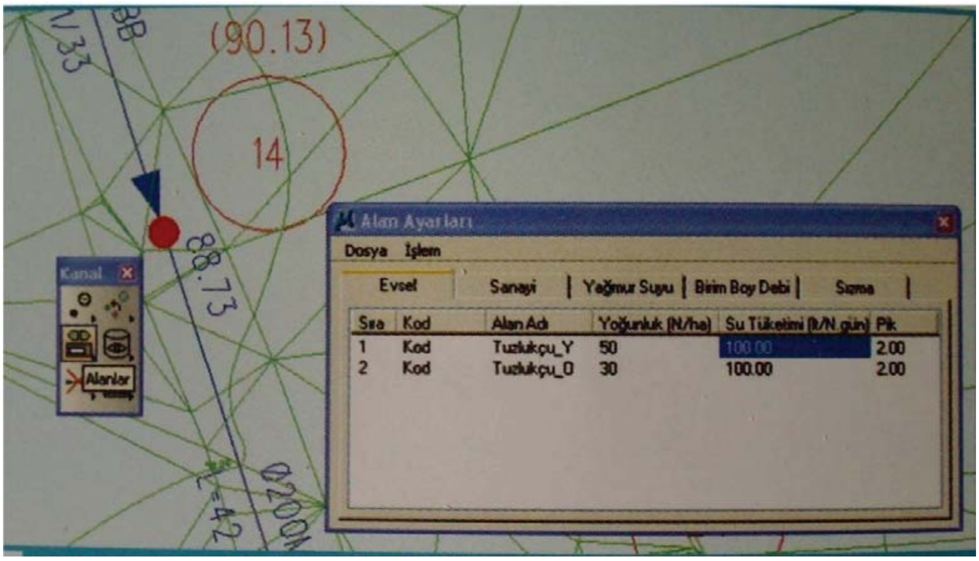


Figure 6.17 Stormwater parameter table in MsKanal program [57].

6.2.1.3 Calculation and Design

A- Calculations with the formulas of Darcy/Colebrook, Manning and Kutter,

B- Values like maximum drop depth, maximum depth of excavation, viscosity can be changed before designing, can be redefined and redesigned again and again,

C- Flow rate calculations by population density coefficient, catchment area method can be selected,

D-Flow direction of the pipes in the system can be configured by “Sort Pipe” command before designing,

E- In design, criteria, various parameters like velocity, slope and flow rate ratio, and tolerance values can be changed and redefined for each diameter.

F- In stormwater calculation and design, Time Intensity Frequency Curves can be determined by both equation and by raw data.

G-Besides circular section, box trapezium sections can be defined and designed in stormwater projects [57].

Figure 6.18 Stormwater pipe parameters in MsKanal program [57].

6.2.1.4 Profile

Profile of required location, can be taken automatically at once, can be saved into files, and printed out before or after calculation [57].

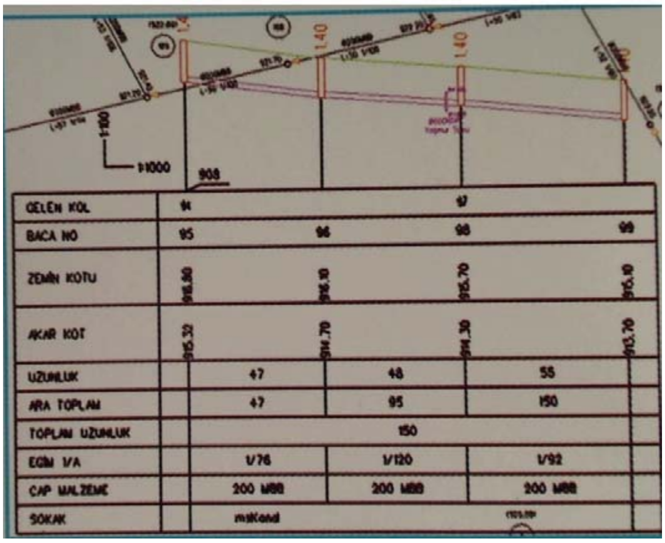


Figure 6.19 Longitudinal cross-sections of pipes in MsKanal program [57].

6.2.1.5 Visual, Thematic Mapping

Results of the model can be turned into a colored thematic visual map on the basis of manhole, pipe and area and calculated values. For example, pipe can be colorized according to diameter, velocity, material and flow rate ratio or manhole as per depth and type [57].

Figure 6.20 Shows a colored pipe outlines in MsKanal program [57].

6.3 Comparison between SewerCAD and MsKanal

Table 6.4 Comparison between SewerCAD and MsKanal

SewerCAD	MsKanal
1- The program runs on AutoCAD software.	1- The program runs on Microstation V8, 8i, and XM software.
2- Used for Sanitary Sewer System only (Storm CAD is for storm sewer system design)	2- Used for both Sanitary and Storm Sewer System.
3- Able to insert different pipe materials.	3- Unable to insert different pipe materials.
4- The existing shapes are: Circular, Arch, Box, and Elliptical (both vertical and horizontal) cross sections.	4- The existing shapes are: Circular, Egg, and Box trapezium cross sections.
5- There is no fullness ratio percentage selection (d/D) in program constraints.	5- Fullness ratio percentage selection (d/D) is available in program constraints.
6- The program is able to calculate total capital cost of construction.	6- The program unable to calculate total capital cost of construction.
7- In the design, loading criteria can be inserted in three forms; Hydrograph-Flow vs. Time, Unit Load-Unit Type and Count, and Pattern Load- Base Flow and Pattern.	7- In the design, loading criteria can be inserted in Unit Load-Unit Type and Count only.

6.4 Comments

Despite the fact that both programs are advanced and powerful, still, there are some aspects that need to be modified in order to ease the calculation and increase the choices and consider the regional constraints and limitations. This is particularly important for developing countries where the conditions and constraints are significantly different from those in the developed ones.

Regardless of the suitability/applicability of these two programs in developing countries, the current drawbacks that should be modified either in later versions or taken into consideration in other programs may be summarized as follows:

A- Not having the fullness ratio percentage in the program pattern (in SewerCAD program).

B- Error messages do indicate the reason for the error but do not propose or indicate to the way to improve the design or solve the problems.

C- In case of selecting the automatic design option (in SewerCAD), the user has to input several alternatives manually in order to enable the program to run automatically.

D- The lack of optimal design in terms of cost and pipe quality.

E- The lack of having cascade manholes in case of having large drops.

F- The lack of recommending or imposing limits to the distance between two manholes in relevance to being too short or too long.

G- The lack of providing volume and/or cost calculations regarding excavations.

H- The lack of having calculations regarding external loads (carry load). This could be achieved through simply input to the type of soil and its resistance to pressure.

I- The inability of inserting/adding different sewer pipe cross sections in to program constraints.

In fact, design stage varies according to the local conditions of the region in concern. Generally, it seems that the ready programs for sewer system design are more easily applicable within developed countries, while the need for some modifications on such programs appears to be more in developing ones.

CHAPTER 7

CONCLUSION

7.1 The Existence of Advanced Technologies in Sewer Systems

There is a continuous need to investigate the existing common problems in sewer systems, and find the relevant causatives. In general, these causatives appear to be relevant to the lack of financial sources and/or good management. The number and severity of such problems are observed to be significantly more in developing countries.

It is always necessary to attempt to solve the existing problems even though this may not appear feasible or easy. The use of advanced technologies requires continuous follow up, understanding and sensitive financial evaluation through some preliminary feasibility studies. This may be feasible to be applied in developed counties, while in developing countries the case is not the same.

The main reasons for not evaluating advanced technologies as a solution to the common problems in developing countries are the following:

A- The lack of significant cooperation among the different municipalities of different cities within the same country.
B- The complicated bureaucracy.
C- The difficulties encountered in coordinating execution works among the different government and private sectors.

7.2 Investigating the Efficiency of Non-Circular Pipes

There is a lot of uncertainty regarding whether spending more money would worth the implementation of egg-shaped cross sectioned sewer pipes and similar other non-circular cross sections. Numerical investigations shows that the improvement in using Non-Circular cross sections is limited and frequently would not worth the required extra cost, particularly if the matter is relevant of renovation of existing systems. It may worth the cost and effort to a limited degree for newly constructed projects, particularly for pipes laid on gentle slopes. The results of the numerical investigations in this research appear to be significantly interesting regarding the efficiency of non-circular pipes in increasing velocity for low flows when compared with the circular section. This research indicates an efficiency that is far less than those declared by previous researchers, and by some companies that applies non-circular cross section for sewer systems.

This difference is likely to be due to the difference in the strategy followed regarding the numerical comparison. In fact, the sources of previous work in this subject, which are literature and contacted companies, were not clear at all regarding their strategy followed in the comparison process. Such clarity in the strategy is essential to enable for a true comparison between the different cross sections.

7.3 The Applicability of Package Programs for Sewer System Design

Generally, the package programs prepared for the design of sewer system are imported from developed countries. Most of these programs are of high quality and arranged to be applied in the countries of origin. However, these programs frequently show some limitations in their applicability in developing countries. These limitations are due to one or more of the typical problems observed in developing countries. Such problems are not considered during the design of these programs simply because they do not exist in the countries of origin. These typical problems or deficiencies are the following:

A- The lack of data and statistics,

B- The instability of city planning which frequently results from sudden changes on the population density and/or changing the purpose of some sectors in the city in concern (zoning), C- The lack of high quality execution of the projects,

D- The lack of regular maintenance,

E- The relatively low standard of education which influence the use of sewer systems.

7.4. The Difficulties in Applying Advanced Technologies in Sewer Systems

Solving financial problems is seldom the only way to provide and apply advanced technologies (i.e. detector robots, laser systems for measuring flow discharge, SCADA systems, and the like) in developing countries. It is observed that improving the management/administration of sewer systems along with improving the qualification of the technical staff is equally important.

In fact, an overall and precise evaluation of the cost of overcoming sewer system problems in developing countries is likely to be higher than the cost implementing advanced technologies that may prevent the occurrence of most common problems in the first place. However, the selection of the proper/suitable method of the advanced technologies that are recently available in the market remains an extremely sensitive task. This task is partly due to the advantage/s of the advertised advanced technology being exaggerated and/or due to the implicit expenses of maintenance that do not appear during the construction/installation.

The lack of financial sources may be related to either the general poor financial condition of the country and/or to the lack of wise distribution of allocation of budget for the different government sectors. The lack of good management may be due to the general lack of highly qualified staff and/or to the fact that most sensitive positions seem to be given to politicians rather than to existing qualified ones

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