# GLASS REINFORCED PLASTIC (GRP) SEWERS REHABILITATION (A CASE STUDY): INVESTIGATION AND PERFORMANCE ANALYSIS

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## ABSTRACT

Sewer rehabilitation is defined as all aspect of upgrading the performance of sewerage system, it includes renewal of a sewer by new construction, reinforcement with duplicate sewers, attenuation of storm flows, and renovation where the existing structure is retained and improved.

The present study concerns Helwan sewers network which were constructed of GRP sewers, in 1991. The sewer diameters range from 800 to 1800 mm with wall stiffness of 1250 KN/m$^2$. Ground sinking and failure are happening at different location within the contract zone. A sophisticated investigation program has been carried out to identify the present conditions and to choose the proper rehabilitation technique. The investigations done included Closed Circuit Televising (CCTV) inspection for the entire sewer network. In addition, a detailed geotechnical investigation was carried out using the Electric Cone Penetration Test (ECPT) at different locations of the sewer network. The ECPT tests results revealed the stratification and geotechnical characteristics of the fill around and below the sewers were not properly constructed.

This paper presents and analyzes the results of the CCTV inspection of the sewers and also inspects the bedding conditions around the sewer. In addition, the paper highlights the effects of rehabilitation on sewer capacity. Usually rehabilitation decreases the sewer carrying capacity due to reduction of the sewer cross-section area. The degree of sewer flow reduction due to rehabilitation depends upon many factors, include the percentage of deformation, and the rehabilitation material thickness. In the present study although the rehabilitation will decreases the sewer caring capacity due to the reduction of the cross-sectional area by lining it does not decrease the required sewer capacity in many locations.

## INTRODUCTION

The in-situ response of GRP-pipes to the fill which overlies the pipes is dependent on the stiffness of the pipe itself and the stiffness of the bedding (the structural fill around and below the pipe). The bedding works as a supporting medium to support the pipe, which partially/fully supports the fill above the pipe and the surcharge loads at ground surface. The pipe-bedding system can be visualized as a circular beam which is subjected to vertical loading (from fill above pipe crown and loads at ground surface) and is supported by a group of Winkler springs. The higher the stiffness values of the springs, the less the deformation the springs and pipe reveal. In other words, the deformation of the pipe will be increased with the weakness of the bedding. Also, the stiffer the beam (pipe-cross section) the less deformation the pipe body reveal. The GRP producers specifications require the use of coarse sand (and/or fine gravel of grains up to around 20mm in diameter) as bedding around and below the GRP pipes. This fill is required to be compacted to a dry density of at least 90% of the maximum achievable dry density from Proctor test. These specifications should be strictly incorporated during construction to develop a stiff supporting medium around pipes.

The sewer in the present study has a depth rage from 2 to 5 m below the ground surface. The stiffness of the GRB sewer is 1250 $KN/m^2$. Unfortunately, there were some failure had been accompanied by remarkable ground sinking. These failures initiated the current study for the assessment of the entire sewerage system within the contract zone and hence recommend the appropriate rehabilitation methodology. The non digging technologies for sewer rehabilitation not only eliminates the inconvenience of open cut, but also may be more economical than the renewal due to saving the cost of surface restoration, trenches excavation and side support, and disturbance of the traffic and other underground utility. In the field of rehabilitation some terminologies are commonly used such as renewal, renovation, replacement and repair. These terminologies have the following meanings as used in this study.

- ***Rehabilitation:*** All aspects of upgrading the performance of existing sewer systems. Structural rehabilitation includes repair, renovation, and renewal.
- ***Renewal*:** construction of a new sewer, on or off the line of an existing sewer, the basic function and capacity of the new sewer is the same of the old sewer.
- ***Renovation:*** Method by which the performance of a length of sewer is improved by incorporating the original sewer fabric.
- ***Replacement:*** Construction of a new sewer, on or off the line of an existing sewer. The function of the new sewer may include improvement or development work.
- ***Repair:*** Rectification of damage to the structural fabric of the sewer and the reconstruction of short length, but not the reconstruction of the whole of the pipeline.

## STUDY PLANE

An extensive investigation program has been carried out in order to decide on the appropriate rehabilitation method. Because of the fact that the GRP sewer gain some of its rigidity from the surrounding, the investigation program did not only investigate the condition of the sewer but also extended to the bedding condition. Figure 1 shows the elements of the work plan.

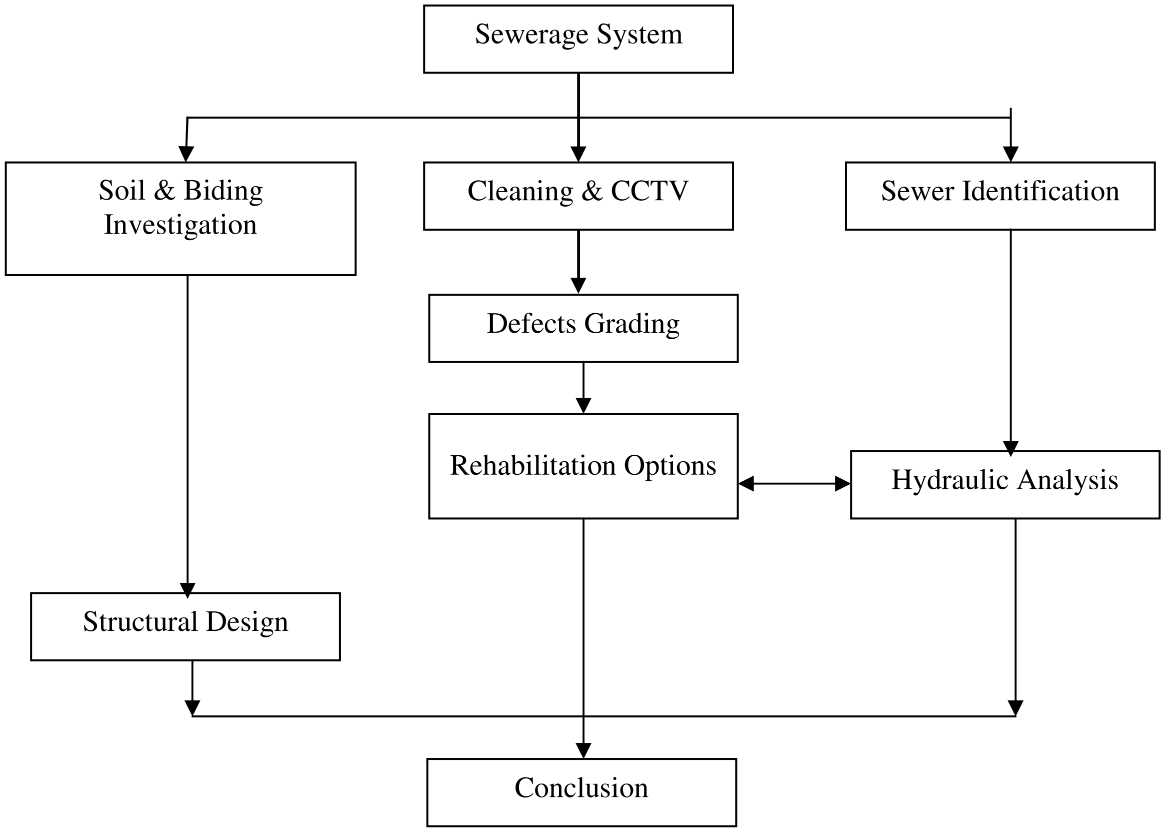


**Figure 1 Study Work Plan**

A geotechnical in-situ investigation program has been carried out to investigate the geotechnical characteristics of the bedding around the pipes. In this program, twenty electric cone penetration tests (ECPT) were carried out at different locations around sewer network. In this test a standard cone together with a friction sleeve were pushed through the ground. The machine used to apply the load to the cone and sleeve had a capacity of 18 ton. Consequently, as soon as the resistance of the soil to the cone penetration approached the aforementioned value, the test was stopped. The tip and side friction resistance are automatically recorded every 20 mm during the advance of the cone. The measured data were then used to interpret the soil type and the geotechnical characteristics of the formations. Relative density and friction angle of cohesionless soils and undrained shear strength of cohesive soils were estimated from the ECPT test results. Also, the deformation modulus, Young's modulus were assessed for the penetrated formations.

The ECPT tests were carried out at 20cm away from the pipe to assess the characteristics of the fill installed during construction operations of the GRP sewer.

The testing results and interpretation are presented below.

## SEWERAGE SYSTEM CONDITION

There were four failure sites within the project zone. When excavating the four sites the sewers found to have a longitudinal crack started at the sewer spocket and extend along the sewer crown. The development of the crack leads to increase of the sewer deformation and ended with the apple shape failure shown in Figure 2. It was noticed that some parts of the collapsed sewer were expanded due to absorption of water by the inner filling material of the GRP sewer after crack / scratch of the thin surface layer of the GRP sewer.

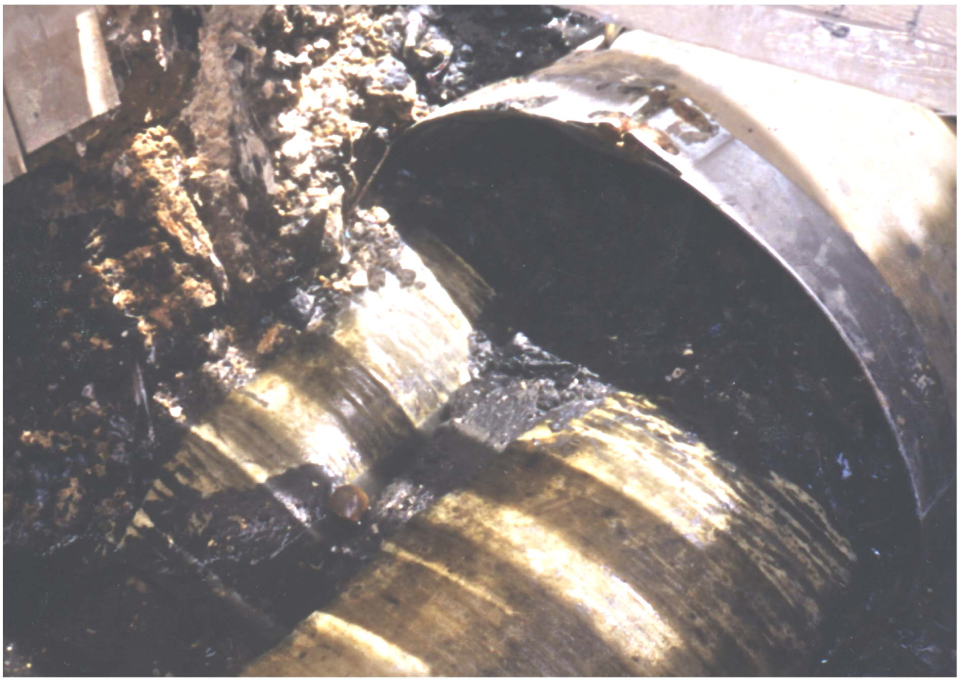

**Figure 2 Typical Failure Shape of the GRP Sewer**

Generally, CCTV can be applied manually for sewer diameter more than 900 mm. Rita, 2000 showed that the use of robotic in sewer inspection not only reduce health risk and potential deaths, but also can lead to substantial saving through increased productivity speed and efficiency. In the present project a robotic was used in televising all the sewer.

The CCTV showed that all the sewers have many segments with defects ranging from small deformation (less than 5 %) up to risky crakes (longitudinal and circular), broken parts and deformation up to 24 %. These serious encountered defects lead to the decision of rehabilitating the entire sewers. Figure 3 shows one of the badly deformed sewers. The proposed rehabilitation systems included two options;

first is renewal of the old sewer online and the second is lining the old sewer. The choice for online and not off line was due to the nature of the streets within the project area, saving the construction cost of new manhole since the manhole are in a good condition and saving the cost of backfilling the old line to avoid future collapses.


**Figure 3 Deformation of the GRP Sewer**

WRc, 1994 proposed a grading scheme for the defected sewers that help taking the proper rehabilitation decision, Table 1. The grading scheme gives grade 5 for the worst condition in which failure might took place and an immediate decision is essential. A recent study by Makar, 1999 recommended not only to apply CCTV for inner sewer inspection but also to inspect the sewer wall thickness as well to determine wither voids exists. In the present project, due to the bad condition for most of the sewers, the decision to rehabilitate the whole sewers eliminates the option of examining the sewer wall.

**Table 1 Sewer Grading Scheme, WRc, 1994**

| INTERNAL CONDITION GRADE | TYPICAL DEFECT DESCRIPTIONS |
|---|---|
| 5 | Already collapsed, Deformation > 10% and broken, Extensive areas of fabric missing, or Fracture with deformation > 10% |
| 4 | Broken, Deformation up to 10% and broken, Fracture with deformation 5 - 10%, Multiple fracture, Serious loss of level, Spelling large, or Wear large |
| 3 | Fracture with deformation < 5%, Longitudinal cracking or multiple cracking, Minor loss of level, More severe joint defects, i.e. open joint (large) or joint displaced (large), Spelling medium, or Wear medium |
| 2 | Circumferential crack, Moderate joint defects, i.e. open joint (medium) or joint displaced (medium), Spelling slight, or Wear slight |
| 1 | No structural defects |

## BEDDING CONDITION

In the current study, interpretation of the cone resistance and friction ratio to obtain the relative density was based on the methods presented by Lanchelotta, 1983, and Baldi et.al, 1986. Interpretation of the friction angle of sandy soil was based on the methods presented by Robertson and Campanella, 1983, Meyerhof, 1956, and Durgunoglu and Mitchell, 1975. Interpretation of the deformation modulus was based on the methods presented by Robertson and Campanella, 1984 while the undrained shear strength was based on the methods presented by Schmertmann, 1976. Figure 4 shows a profile of the soil and stratification at one of the locations of ECPT tests. Table 2 presents a summary of the bedding conditions around the pipes at different locations within the sewer network area. Table 2 shows that the bedding around the GRP-pipes exhibits a relative density range between 30 to 100. In general, the degree of compactness of sand formations can be expressed by its relative density as shown in Table 3.

Comparison of the assessed in-situ relative density with the classification presented in Table 3 exhibits that the bedding state ranges between very loose to very dense with most of the data in the range of medium to dense sand. The sand bedding around the GRP-pipes should be, at least, in a dense state such that a good support is provided to the GRP sewers to minimize its deformation under working loads.

**Table 2: Summary of Electric Cone Penetration Tests Carried out at Different Locations Within the Helwan Area**

| ECPT # | Lower Sewer Half | | | Upper Sewer Half | | |
|---|---|---|---|---|---|---|
| | **Soil Type** | **R.D. Sand** | **Silt/Clay** | **Soil Type** | **R.D. Sand** | **Silt/Clay** |
| 1 | Sand / Sandy Silt | 33 - 73 | x | Sand / Silty Sand | 56-90 | |
| 2 | Sand / Sandy Silt | 37 - 78 | x | Sand / Sandy Silt | 31 -74 | x |
| 3 | Sand | 63 - 100 | | Sand / Sandy Silt | 77 - 34 | x |
| 4 | Sandy Silt / Sand | 77-100 | x | Sand / Sandy Silt | 34 - 39 | x |
| 5 | Silty Clay | | x | Sand / Sandy Silt | 83-100 | |
| 6 | Sandy Silt / Sand | 75 - 100 | x | Sand | 82 - 99 | |
| 7 | Sand / Sandy Silt | 36 -100 | x | Sand / Sandy Silt | 30 - 39 | x |
| 8 | Sand | 40 - 47 | | Sand / Sandy Silt | 33 - 37 | x |
| 9 | Sand | 58 - 81 | | Sand | 79-94 | |
| 10 | NO data is available from ECPT, refusal was attained before reaching to the pipe zone | | | | | |
| 11 | Sand / Sandy Silt | 41 -100 | x | Sand / Sandy Silt | 32 - 61 | x |
| 12 | Sand | 48-82 | | Silty Sand | 45-80 | x |
| 13 | No data is available from ECPT, may be because of reaching to refusal | | | | | |
| 14 | Sand | 76-95 | | Sand | 76 - 59 | |
| 15 | Sand | 100 | | Sand | 50 - 100 | |
| 16 | Sand | 92 - 100 | | Sand | 88 - 75 | |
| 17 | No data is available from ECPT, may be because of reaching to refusal | | | | | |
| 18 | Sandy Silt / Sand - ECPT reached to refusal before reaching to pipe invert | | x | Sand / Sandy Silt | | x |
| 19 | No data is available from ECPT, may be because of reaching to refusal | | | | | |
| 20 | No data is available from ECPT, may be because of reaching to refusal | | | Sand / Silty Sand | 35 - 100 | x |

R.D. Relative density range of the encountered cohesionless soils, X indicates that silt/clay zones were encountered during investigation

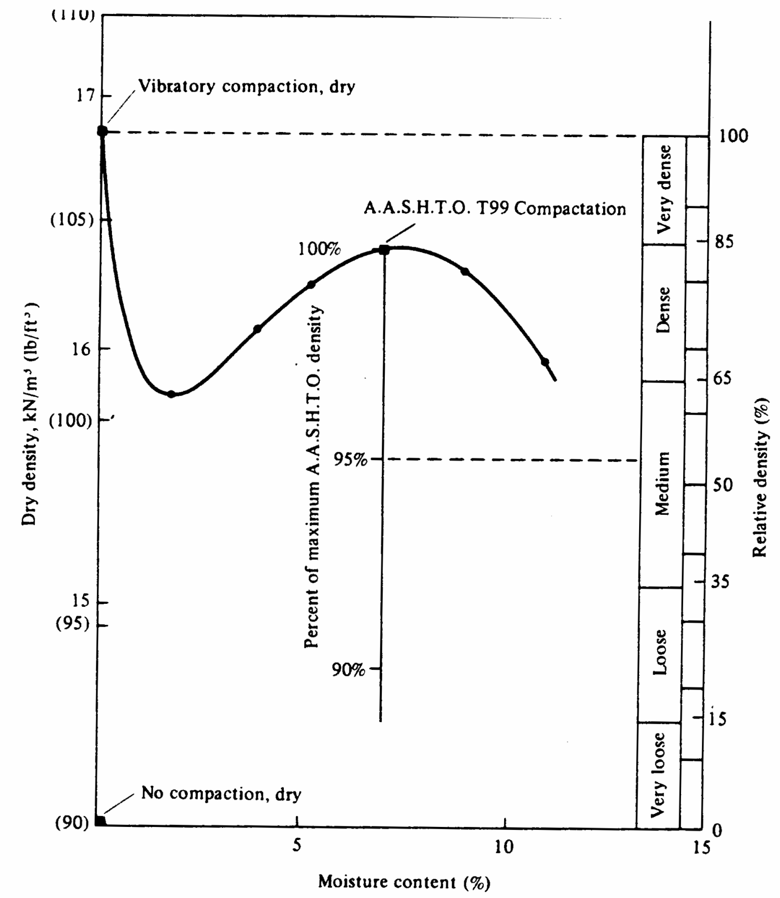


**Figure 4 Moisture Content-Dry Density Relative Density Relations for a Sandy Soil, Spangler (1982)**

**Table 3: Relative Density-Sand Compactness Status**

| | | | | | |
|---|---|---|---|---|---|
| Relative Density | 0-15 | 15-35 | 35-65 | 65-85 | 85-100 |
| Compactness Degree | Very Loose | Loose | Medium | Dense | Very Dense |

During construction work, the sand cone test, due to its simplicity and cheapness, is conventionally used as the quality control test for compaction work of cohesionless soils. It should be noticed that high degree of relative compaction may result in an erroneous implication. For example, the dry density-moisture content-relative density curve shown in Figure 5 exhibits that the considered sand specimens can be compacted to a relative compaction of 95% with practically no control on moisture content, but the corresponding relative density would be only 54%, which corresponds to a sand at a medium state. Consequently, the use of a relative density (such as 80% relative density) would be a better project specification than a relative compaction of 90 or 95% as conventionally adopted in the current practice. In other words, the in-situ dry density is estimated for the compacted sand in the field by the sand-cone as conventionally carried out and then the relative density of the compacted layer in the field is determined as:

$$Dr = [\gamma_{max} (\gamma_{field} - \gamma_{min})] / [\gamma_{field} (\gamma_{field} - \gamma_{min})]$$

Where $\gamma_{field}$ is the measured dry density and $\gamma_{max}$ and $\gamma_{min}$ are the maximum and minimum dry densities determined from the laboratory relative density test. In summary, the relative density test is carried out for the bedding material instead of the Proctor test and consequently the relative density of the bedding can be assessed once the sand cone (or another appropriate field) test is carried out in the field.

Table 2 exhibits also that silt and/or clay zones were encountered within the bedding during investigation. Clean coarse sand and/or fine gravel (up to 20mm grains diameter) should be used as a bedding material.

## REHABILITATION OPTIONS:

The lining material can be classified to either polymeric or cementing material. Polymeric martial is sub-classified into glass reinforced plastic “GRP”, polyester Resin concrete “PRC” polyester Resin polyethylene “PE”, polypropylene “PP” or un-plasticised polling chloride “PVCU”. The cementing material is subdivided into glass reinforced cement “GRC”, Gunite, or Ferro-Cement.

The polymeric material is more suitable for applications in wastewater, than the cementing material especially if there are possibilities of septic sewage. The critical properties that govern the choice of the lining material include chemical resistance, abrasion resistance and mechanical properties. For domestic wastewater all types of polymeric materials are suitable as liners. Material abrasion resistance is related to the relative weight loss. Table 4, WRc, 1994 summarizes relative abrasion resistance of different lining material that may be used for sewer renovation.

**Table 4: Lining Material Properties**

| Material | Relative weight loss, % |
|---|---|
| Polyethylene | 1 |
| Polyester resin | 2-4 |
| GRP | 2-10 |
| PRC | 4-14 |
| Clayware | 6-10 |
| PVCU | 8-15 |

The utmost performance of the GRP lining can be maintained as long as the protective thin surface layer is kept un-cracked / unscratched. If this layer is damaged during installation or operation and maintenance degradation will be started and accelerated. The effect of erosion upon the structural performance of a lining is related to the initial wall thickness. For example, loss of 2mm from 40mm thick PRC panel would reduce its tensile load carrying capacity by 5 %. The same wall thickness loss from a 10mm thick GRP lining would result in a 20 % reduction. This consequence would need to be considered carefully in circumstance where substantial erosion was likely, WRc, 1994

## STRUCTURAL DESIGN OF LINING

WRc, 1994 classify the structural design of linings to type I and type II lining. In type I lining the renovated sewer is considered to be acting as a composite section, consisting of the existing sewer, grout and lining. It is assumed in the design that these three components are bonded together and the grout is stiff and strong enough to transfer stress to the lining. The design philosophy of the type I approach is to create a rigid structure that carries all ground and traffic loads. A cost-effective design is achieved by utilizing the existing sewer to carry the compressive forces while the lining carries the tensile forces. Type I technique should not be used in non man entry sewers (less than 900 mm) and only in man entry sewers where high confidence annulus grouting can be achieved, or where an in site coating is considered suitable. A good bond is required to carry the shear force between the old sewer and grout and the lining and grout.

Type II is designed to act as a flexible pipe with the old sewer, no bond is required between the lining and the old sewer. The design philosophy of type II lining is to install a flexible liner that utilizes the existing sewer and ground support where possible to produce a cost effective renovation system.

## HYDRAULIC ANALYSIS

The Hydraulic properties of the sewer will be changed by rehabilitation either due to improving the roughness of the sewer (increase the sewer flow capacity), or due to reduces the cross-sectional area of the sewer and its hydraulic radius due to lining (decrease the sewer flow capacity). The degree of reducing the sewer cross-section area and hydraulic radius depends on the lining thickness and mainly upon the shape of the lining whether a closed fit or circular. Figure 6 shows the schematic diagram for the two lining shapes. The hydraulic parameters of the lined sewer by the two options (closed fit, and circular) was calculated for 10 % deformed sewer with different sewer diameter and lining thickness and compared to the original values and summarized in Table 5. It was assumed that the deformed sewer will has an elliptical shape. The hydraulic parameters were calculated for ¾ full ratio.

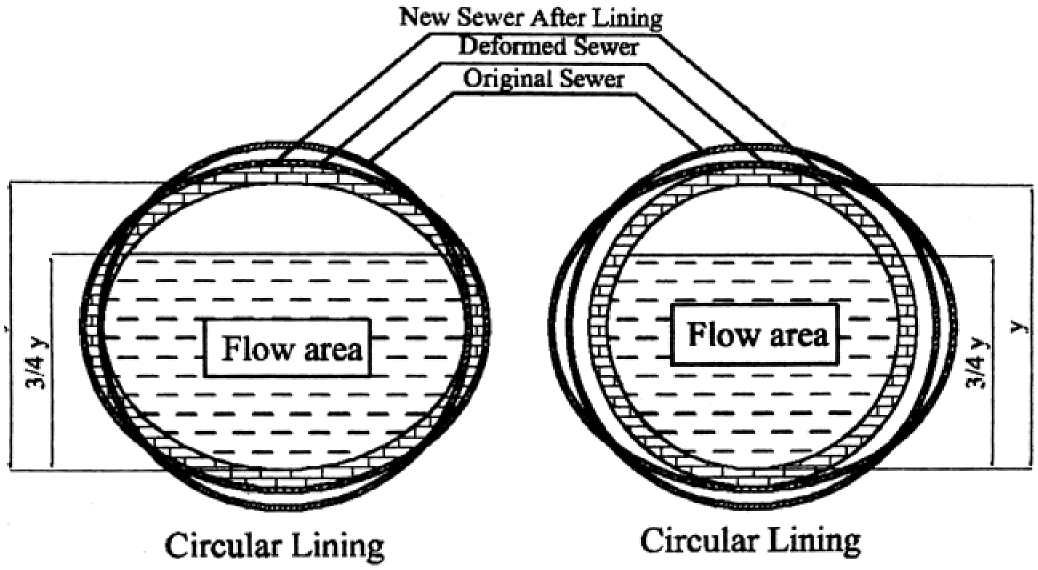


**Figure 6 Lining Shape**

**Table 5: Effect of Lining on Cross-section Area and Hydraulic Radices**

| Diameter mm | Lining thickness mm | Closed fit lining | | Circular lining | |
|---|---|---|---|---|---|
| | | % of New area/ Original (3/4 full) | % off new $R^{2/3}$ / Original | % of New area/ Original (3/4 full) | % off new $R^{2/3}$ / Original |
| 800 | 40 | 79.95% | 94.44% | 64.11% | 77.49% |
| 800 | 50 | 75.50% | 80.56% | 60.15% | 75.96% |
| 800 | 60 | 71.29% | 79.01% | 56.19% | 74.18% |
| 900 | 50 | 78.32% | 92.19% | 62.30% | 85.59% |
| 900 | 60 | 74.02% | 88.89% | 58.79% | 83.78% |
| 900 | 70 | 70.31% | 87.39% | 55.47% | 82.28% |
| 1200 | 60 | 79.89% | 98.10% | 63.85% | 94.29% |
| 1200 | 70 | 76.92% | 97.69% | 61.21% | 92.93% |
| 1200 | 80 | 73.96% | 96.74% | 58.68% | 91.85% |

The above table can be used to estimate the lined sewer carrying capacity based on the above mentioned assumptions. The table shows that the closed fit lining reduction factor is lower than that of the circular type and the differences decreases as the original sewer diameter increases. The proposed lining thickness was chosen according to the proposed thickness by many of the lining specialties companies. In many cases in the present project lining will reduce the sewer capacity by value ranged from 60 to 20 %. In many cases in the present project the lined sewer capacity is still more than that the sewer can receives. The reason is that the sewers slope in many locations is close to the max allowable slope and the full ratio of the original line at peak flow is less the ¾ full.

## CONCLUSIONS

Based upon the investigations mad and limited to the assumption mentioned above the following conclusions can be made;

- The noticed failure pattern of GRP-pipes within the area under consideration may be refereed to a combination of use of GRP-pipes of low stiffness and improper backfilling around the pipes during construction.
- The stiffness of the GRP sewers should be carefully calculated and chosen to provide adequate support for the overlaying fill and ground loads.
- Hydraulic examination of the lined sewer is essential.
- Closed fit lining is better than circular lining with respect to the sewer carrying capacity.
- Clean coarse sand and /or fine gravel should be strictly used as bedding material around and below the pipes since these materials provide higher stiffness than silt/clay materials.
- Relative density should be used in compaction work specification as the quality control parameter instead of the use of a relative compaction of 90 or 95%. It is recommended to specify a relative density of 80%, at least, as a control parameter.

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