FAISALABAD AREA UPGRADING PROJECT

Research & Design

APPROPRIATE DESIGN STANDARDS AND CONSTRUCTION SPECIFICATIONS FOR TERTIARY SEWERAGE SYSTEMS

Faisalabad, Pakistan

(January 2002)

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DFID Department for International Development

Fda Faisalabad Development Authority

WASA Water & Sanitation Agency

GHK

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Front Cover: Testing of sewerage pipes to destruction.

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Khatib Alam and Jonathan Parkinson
(January 2002)

DEFINITIONS AND ABBREVIATIONS

Access chambers

Access chambers are constructed on tertiary sewers to make household connections to the lane sewer and to enable inspection and maintenance.

CBO

Community based organisation

Domestic wastewater

Wastewater produced by residential households consisting of toilet wastewater and sullage.

Dry weather flow

Flow of wastewater that is produced during dry weather

Gully trap

Gully traps are designed to allow the entry of sullage from household connections into the tertiary sewerage system whilst providing a barrier to the entry of gas and odours into the home.

Haudi

See interceptor tank

Interceptor tank

Commonly know as *haudis*, interceptor tanks consist of a small chamber constructed at the household level which acts as a connection box for all the pipes discharging household wastewater and stops the ingress of heavy solids into sewerage system.

Katchi abadis

Areas of unplanned urban development consisting of informal settlements which are generally not served by the municipal infrastructure and services.

Manholes

Manholes are required where the sewer is deeper than the maximum depth of the access chambers and the chamber must be large enough for the entry of a man for inspection, cleaning, and maintenance. Manholes are constructed at intervals along a sewer line where there are intersections, changes in direction of the sewer, gradient, or sewer diameter.

NGO

Non governmental organisation

PHED

Public Health and Engineering Department

Primary sewer

The primary sewerage system consists of the trunk sewers that convey wastewater to the location of disposal. This may include pumping. Primary sewers have no direct household connections.

Secondary sewer

The secondary sewerage system consists of the sewers that receive wastewater from tertiary sewers and from the adjacent houses along the street in which the sewer is laid.

Sullage

Sullage consists of household wastewater from washing and bathing domestic activities.

Tertiary sewer

Infrastructure serving a lane or street at the local level.

FOREWORD

In Pakistan, the need for affordable sanitation for all is widely seen to be a prerequisite for social and economic development. The livelihoods of urban communities can be significantly improved through the provision of water supply and infrastructure to drain wastewater. Experiences from Faisalabad illustrate that poor communities are willing to participate in the provision of tertiary sewerage infrastructure provided their voices are heard and that they are treated as equal citizens in the development process.

Over the past 7 years, Faisalabad Area Upgrading Project (FAUP) has demonstrated that communities are willing to be actively involved in the planning process, to offer services to assist with the construction of the sewers, and to contribute towards the capital cost of the infrastructure. At the same time, FAUP has worked alongside the Water and Sanitation Agency (WASA) in Faisalabad towards developing an improved understanding of the needs of urban communities, particularly those in low-income areas, and specifically those relating to water supply and sewerage infrastructure. Through the sustained efforts of the FAUP teams working in the four pilot areas and, in particular the Community Infrastructure Unit, this process has proved to be mutually beneficial for both WASA and the communities themselves.

The experiences from Faisalabad demonstrate the benefits that may be achieved where the government agency plays an active role in promoting partnerships and community involvement in the provision of sewerage infrastructure. The benefits have resulted in comprehensive service coverage in the project areas and improvements in the environmental health conditions relating to improved sanitation and drainage of wastewater.

The development of appropriate standards and design specifications for tertiary sewerage systems has proved to be a critical part of this process. The ratification of the design specifications and official regulation of the connections has subsequently resulted in increased revenue collected by WASA. This report will provide those working for government agencies and non-governmental organisations in Pakistan, as well as representatives of the international donor agencies with documentation of the process that was undertaken over the past 7 years towards developing these standards and specifications.

Chaudhry Zahid Nazir
District Nazim
District Government, Faisalabad
January, 2002

PREFACE

Sewerage is widely used as a means of removing wastewater from low-income residential areas in the cities and towns of Pakistan. In many cases, local facilities have been provided by groups of householders themselves, with or without assistance from NGOs and, more rarely, government departments. While these initiatives have done much to bring about short-term improvements in local conditions, their overall impact has been limited. The reasons for this are twofold. Those schemes that have been implemented without assistance from specialist organisations often suffer from poor design and construction standards. This problem has been partly overcome when assistance has been provided from reputable NGOs but a second problem then arises in that the government sewerage authorities have still to accept the standards adopted. As a result, community-built schemes have no legal status and generate no revenue for the authorities.

On the government side, until FAUP, the only attempts to develop standards and specifications suitable for use in low-income 'informal' areas have been led by international consultants. They have been restricted to specific projects such as the World Bank funded projects implemented in Lahore under the Punjab Urban Development Project. However, the standards and specifications have not been adopted beyond the specific projects for which they were developed and most 'officially' provided sewers continue to use standards and specifications that make them unaffordable to residents of low-income areas.

There is an urgent need to generate consensus on what constitute acceptable standards and specifications for low-income areas. This agreement cannot be reached on the basis of talking alone. Rather, the need is to test a range of standards and specifications under both laboratory and field conditions so as to provide practical demonstrations of what does and does not work. The work described in this case study should contribute to this process. It covered the testing of sewer pipes under controlled conditions and evaluation of the performance of existing FAUP sewers laid with community involvement and utilising non-'traditional' design standards, some of which were adopted from the NGO OPP. It confirms that viable options for local sewerage schemes exist and that it is possible to reach agreement, at least locally, on the standards and specifications that are appropriate for these systems. The challenge for Government is to use these and other findings as the basis to build wide consensus on acceptable standards and specifications for sewers in low-income areas.

Kevin Tayler

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EXECUTIVE SUMMARY

The report provides a comprehensive documentation of a research programme carried out as part of Faisalabad Area Upgrading Programme (FAUP) in partnership with the Faisalabad Water and Sanitation Agency (WASA). The objective of the research was to develop a set of standards and specifications for the design and construction of tertiary sewerage systems. The longer term aim was for these standards and specifications to be accepted by the relevant government authorities and thus be adopted for widespread application in community-based sanitation projects in Faisalabad and other cities in Pakistan.

Existing government standards are unaffordable to the majority of the residents who live in the katchi abadis. Due to the increasing demands from communities and because of limited resources and the inability of WASA to respond to these demands, many communities are observed to construct their own sewers. However, government engineers do not accept the standards of construction which are generally lower than the standards ratified by the provincial Planning and Development Authority. As a consequence, the sewers are not officially recognised and WASA receives no revenue from the households who are unofficially connected to the municipal sewerage system.

Accordingly, it was considered necessary for FAUP to develop a set of design standards and construction specifications to enable the sewers not only to be accepted under the technical scrutiny of the WASA engineers, but also to be affordable to the communities that they are designed to serve. Therefore, as part of the FAUP research programme, alternative specifications for concrete pipes, access chambers and covers were developed and tested for tertiary sewers. The specifications are incorporated in the design details which are presented in this report.

Conventional engineering design of sewerage systems tends to focus on the design and construction but insufficient attention is generally paid to the operational requirements. Maintenance is critical to the sustainable operation of sewerage system, especially due to a lack of efficient systems for solid waste collection which invariably blocks sewers.

Fieldwork was undertaken to evaluate the operational performance of sewerage systems and the implications upon design. The study therefore aimed to evaluate the maintenance requirements of these sewers and carried out some practical evaluation of sewer cleaning equipment.

The procedure of development of appropriate design standards and construction specifications was complimented by discussions with WASA staff, local residents, and representatives of nongovernmental organisations (NGO) to evaluate and document their experiences and to ascertain the level of satisfaction from the community in their investment. These activities were carried out to ensure that technically feasible and economically viable solutions were developed within the existing social and institutional context of Pakistan.

1.0 INTRODUCTION

1.1 Background

In the larger cities in Pakistan such as Faisalabad, the Water and Sanitation Agency (WASA) is the government authority which is officially responsible for the implementation, operation and maintenance of the physical components of sanitation infrastructure. In the smaller cities and towns, these responsibilities are designated to the relevant regional Public Health and Engineering Departments (PHED).

The majority of drainage projects are based upon urban development master plans in which government agencies adopt a traditional approach in which projects are undertaken by contract between the government agency and private contractor. The financing of these projects is often influenced by political motives and the demands from local communities and is prone to inefficiencies in the government administrative systems. The beneficiary communities play a relatively minor role in the planning, design, and operation and maintenance of infrastructure.

Due to rapid urban expansion, the cost of operating and maintaining existing infrastructure, the high investment costs of new infrastructure, and the lack of manpower and financial resources, the financial viability of these government agencies is significantly impeded. As a result these agencies struggle to keep pace with the demand for new services.

There is a considerable backlog in the provision of sewerage infrastructure in the urban areas and many communities, particularly those located in the peri-urban areas on the edge of the city, lack access to household sewerage connections resulting in poor sanitation and wastewater disposal (see Figure 1-1).

Many residents are willing to collaborate with other residents in their street and invest their own money for the construction of local infrastructure and are responsible for the construction of household connections. In this situation, representatives from the relevant community based organisation (CBO) are responsible for purchasing the sewer pipes and for making arrangements for a local contractor to lay the pipeline.

However, the extent of communication and degree of co-operation amongst the members of the community limits the scale of these projects.

Figure 1-1 Typical sanitation problems associated with poor drainage

Where communities are assisted by an external organisation, the scale may be considerably increased and whole neighbourhoods may be mobilised to participate in community infrastructure projects.

As a response to this situation, the Orangi Pilot Project (OPP), an NGO based in Karachi, pioneered an alternative model to the conventional approach towards the provision of sanitation in the katchi abadis of Orangi.

The fundamental principle of the OPP model is to utilise community resources to plan, construct, and manage community-level (internal) infrastructure of tertiary level sewerage, and requires Government agencies to provide secondary and primary sewerage infrastructure (external).

1.2 Faisalabad Area Upgrading project

In 1989 the Government of Pakistan 7th Five Year Plan (1988-93) gave priority to poverty alleviation through investment in social and physical infrastructure and active participation of the poor. Implementation of the 7t' Five Year Plan had, however, been inconsistent. Social sector investment increased much more slowly than anticipated and there have been many delays in improvement of physical infrastructure. Furthermore, progress in improving municipal self-reliance has been limited. In the same year, Faisalabad Area Upgrading Project (FAUP) was agreed between the Government of Punjab, Pakistan and the British Government, through the Overseas Development Administration (ODA). ODA was later re-named as Department for International Development (DFID).

This very large and complex project included improvements in the sectors of infrastructure (water supply, sewerage, solid waste, road, pavements and street lights), health and environmental care, small enterprise development and basic education. All of these sectors were to be undertaken in partnership between local communities and government service delivery line departments in selected four pilot project areas all located in low income katchi abadis and slum areas of urban Faisalabad.

The project also aimed to strengthen the capacity of government agencies to respond to community demands for services, to develop arrangements for cost sharing, and to develop strategies for improved operation and maintenance. The longerterm objective of FAUP has been to develop procedures in government departments that allow replication of the approach in other parts of Pakistan.

As part of its programme of poverty alleviation through community empowerment, FAUP promotes community-based sanitation by facilitating the formation of community groups and encouraging them to develop their own internal capacity to tackle problems and prioritise development needs.

The definition of ‘external’ and ‘internal’ infrastructure relates to the responsibility for implementation (government and community respectively). In terms of the physical infrastructure, the sewerage system may be defined as primary, secondary and tertiary infrastructure (see Figure 1-3).

In the FAUP project areas, the cost of physical infrastructure at the community (tertiary) level is shared between FAUP and the community. All tertiary level projects are implemented through community-based contracts.

Because of the flat topography in Faisalabad, sewerage systems have to be laid to shallow gradients and rely heavily on pumping. In order to facilitate the operation of tertiary services, FAUP has also funded all the secondary level water and sewerage projects in the pilot areas. These have been designed to full WASA specifications and implemented by this Government line department.

1.3 FAUP low-cost sanitation programme

Initially, FAUP adopted standards and construction methods that were similar to those of Orangi Pilot Project (OPP). However, due to the fact that these did not satisfy the government's official standards, WASA was reluctant to adopt these sewers for operation and maintenance.

To address this problem, WASA requested FAUP to develop and recommend a technically appropriate and economic design for communitybased tertiary sewerage that would be acceptable by WASA. This would promote more costeffective sewerage services and communities would know that WASA would take over ownership and operation and maintenance, on payment of the affordable charges based upon an appropriately designed tariff structure.

This report documents the research carried out by FAUP in conjunction with Faisalabad WASA to develop appropriate specifications for the design and construction of tertiary sewerage systems. This work was carried out through the Community Infrastructure Unit, which is a small discrete unit funded through FAUP but operating as part of WASA, and based in WASA's main offices in Faisalabad.

1.4 Funding Mechanism

All projects with the communities (i.e. at the tertiary level) are implemented on a cost-sharing basis (see Figure 1-2). With the exception of education related activities, in all the other sectors i.e. health, environment infrastructure (water, sanitation, paving, solid waste) and small enterprise development the partnership with the communities is on a 50%-50% cost-sharing basis. In the case of education, the communities contribute 15% whilst the project contributes 85% of the funds.

Figure 1-2 Flow of funds in the project

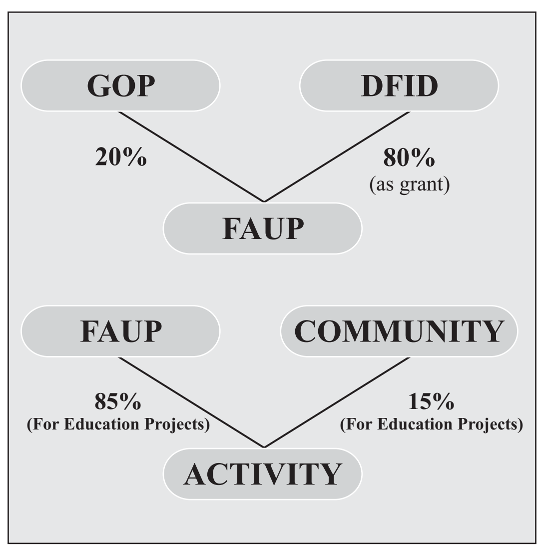
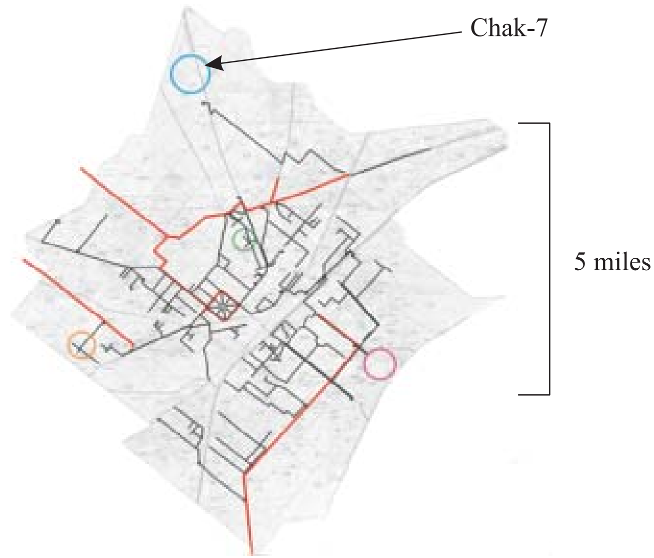


Figure1-3 Primary, Secondary and Tertiary level sewerage infrastructure

Primary level sewerage infrastructure

The figure shows the city of Faisalabad illustrating the primary level sewerage infrastructure which includes large diameter trunk sewers, open-channel drains, and pumping stations.



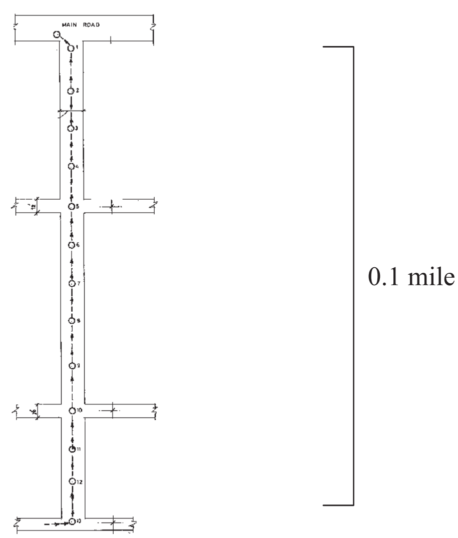
Secondary level sewerage infrastructure

Secondary level sewerage infrastructure consists of collector sewers at the neighbourhood level. The diagram shows the secondary sewers serving the community of Chak-7 on the periphery of Faisalabad which consist of 12 - 18 in. diameter pipes and brick manholes.

Lane in NH-C in Chak 7

Tertiary level sewerage infrastructure

The diagram on the left shows a lane in NH-C of Chak-7. Tertiary level sewerage infrastructure includes lane sewers, access chambers, household connection chambers and interceptor tanks (haudis).



Note : distances are only indicative of scale

1.5 Definition of standards and specifications

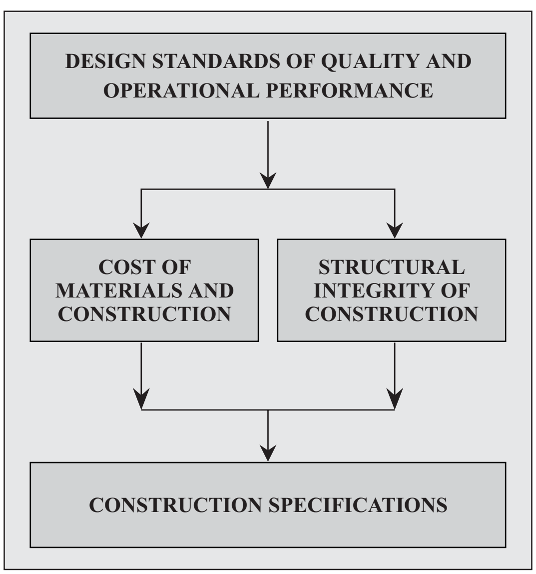
Designated design standards are associated with the objectives of operational performance and durability of infrastructure. Design standards are therefore concerned with what is to be built rather than how it is built or from what materials are used for construction. In particular, standards relate to hydraulic and structural performance

Standards are also required to ensure that infrastructure is cost effective and affordable for the communities that they are designed to serve. These include both the capital expenditure of constructed infrastructure as well as the recurrent maintenance costs. Recommended procedures are also required to ensure that standards are applied properly.

Specifications are necessary to ensure that different agencies and organisations construct sewerage systems according to a uniform procedure. This is especially important for sewers which are interconnected and where one agency is responsible for operating and maintaining the whole system.

Specifications are necessary to ensure that sewerage systems are constructed to perform according to designated standards and technical parameters that are required to ensure uniformity in construction. Specifications are required for construction to provide the contractor with the necessary information for workmanship and are primarily intended as a guide for construction.

Figure 1-4 Factors influencing design and construction specifications



Construction details of specifications need to be presented in a way that is readily understandable to those working on site. Failure to provide those working on site with sufficiently detailed specifications for construction may result in adjustments being made on site based upon the assumptions of the construction workers.

Specifications are important to achieve performance standards, but these standards will only be achieved if the specifications are implemented correctly. Figure 1-4 illustrates the relationship between standards and specifications.

1.6 Existing design standards and Specifications

Government-funded projects adopt design and construction specifications derived from American and British standards. These are ratified by the Punjab Planning and Development Department and adopted by the Water and Sanitation Agencies and Public Health Engineering Departments in Pakistan.

1.6.1 Design standards

Minimum pipe diameter

The minimum pipe diameter according to the official government specifications (PHEW, 1986) is 9 in. The majority of tertiary-level sewers comply with this standard, although some community-based sewerage schemes use 6 in. diameter pipes for lane sewers. In the early stages of FAUP up until 1997, 6ft. plain-ended pipes of commercial grade were used for construction of tertiary sewers. Although these pipes are known not to comply with the BS or ASTM standards, general observations indicate a satisfactory structural performance. However, due to the reluctance of WASA to adopt these sewers for operation and maintenance, FAUP changed to using WASA standard 8 ft. pipes with spigot and socket joints.

Sewer gradient

Conventional sewer design is based upon the principle of self-cleansing velocities to flush deposited material from the sewer. The Revised Design Criteria for Water Supply, Sewerage and Drainage Schemes (Punjab PHED, 1986) state that the desirable minimum design velocity should be 2.5 ft. sec 1. However, design criteria state that in difficult situations, i.e. where slopes are limited, the minimum acceptable velocity may be reduced to 2.0 ft sec^{-1}.

Depth of sewer

The minimum cover specified for 9 in. pipes by BS5911 is 3 ft. but the minimum cover according to PHED (1986) is 2.5 ft. from the crown of sewer to ground level. However, many pipes in lanes have been laid by private contractors and community organisations with cover depths which are lower than this.

1.6.2 Structural specifications

The structural specifications for sewer pipes adopted by the engineering authorities in Pakistan are based upon relevant British Standards (BS5911 Pt. 100) for 9 in. pipes and less, whereas the standards used for pipes greater than 9 in. are based upon the relevant American Engineers standards.

The wall thickness of the pipes varies according to the amount of reinforcement used. The official standards specify a pipe wall thickness of 7/8 in. - 1 in. rather than the 1.5 in. required by BS5911. Often an increase in wall thickness is required to meet the BS5911 structural specifications. Pipes manufactured in small nonapproved yards are normally 6ft. long with a wall thickness of 1 in.

Concrete specification for sewer pipes

BS 5911 requires crushing strength and bending moment resistance values of 25kN/metre (1680 1b/ft.) and 8.1 kNm (5850 lb.ft.) respectively. To achieve these performance specifications, BS 5911 recommends a pipe wall thickness of 1.5in. (38mm), a minimum cement quantity of 360 kg/m3 (equivalent to a 1:2:3 mix), and a maximum water:cement ratio of 0.45. BS5911 specifies a minimum concrete material ratio of 1:1.5:3 (cement: sand: aggregate) and a structural performance criteria of crushing load 25kN/m.

Reinforcement

According to BS591 1, reinforcement is not required for small diameter pipes, but in order for pipes to attain an acceptable level of structural integrity they are heavily reinforced. The amount of reinforcement varies but generally consists of four or more 3/16 in. diameter longitudinal bars with hoop reinforcement provided by spirally wound wire. Typically, 14 lbs. of steel reinforcement is used to fabricate an 8 ft. pipe of 9 in. Diameter.

Pipe jointing

Government systems use spigot and socket pipes which should conform to the specifications according to the British Standard BS 5911, Pt 100 (1988), whereas many private developers and NGO systems use plain-ended pipes. Flexible spigot and socket joints incorporating a rubber ring to form a flexible seal between the pipes are specified by BS 5911. However, in practice these may not be used and where plain-ended pipes are used, the joints are made using jute strips soaked in cement paste which are wrapped around the pipe ends forming rigid joints.

Pipe bedding and backfilling

The PHED specifications for bedding for sewers above sub-soil level are derived from A.S.T.M. The specifications state that sewers up to 12 in. diameter should be laid on a bed of sand. According to the government specifications, trenches should be backfilled with selected excavated material. However, in general, private developers and contractor responsible for sewer construction in kachi abadis pay little attention to these specifications.

Manholes and access chambers

Most manholes and chambers in Punjab are circular in cross-section and are constructed of brick on a mass concrete base. Alternative designs for chambers have been used for sewers at lower depths, as these are considered to be technically appropriate for lane sewers and are also considerably cheaper. Generally these are circular in cross-section and are constructed using cement which is cast in situ using moulds.

Access chambers covers are reinforced concrete and are less robust than the standard WASA approved manhole cover. The covers are usually constructed on site and are cast using a simple concrete mould. These circular concrete access chambers have been used in many locations, but do not have the formal approval of the government agencies.

1.7 Rationale for the development of appropriate specifications

In the adoption of the existing specifications described above little account is made for the fact that standards may not be suited for adoption in these areas where the conditions are significantly different from those in the UK and USA. The main technical differences are summarised as the difference in Box 1-1.

Box 1-1 Technical reasons for appropriate Standards

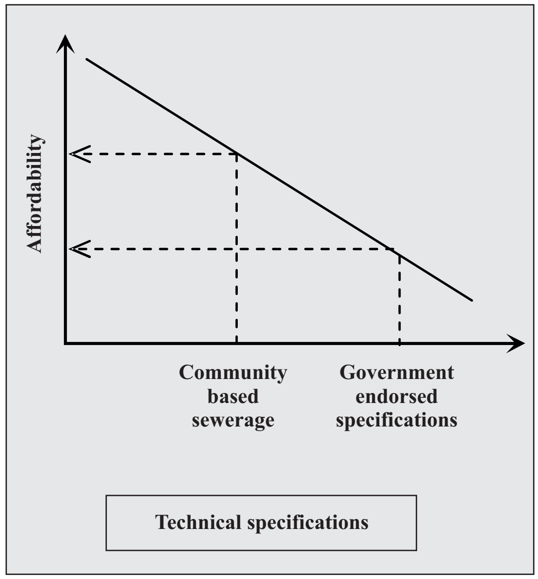
Imposed surface loads
The imposed loads caused by traffic passing over the road surface is considerably less in narrow residential lanes than in busy streets that are regularly used by larger commercial traffic.
Construction techniques
In Pakistan, construction techniques are very different from those in the UK and in USA. Design specifications should also take account of the local availability of materials and construction practices.
Solid waste management
Due to poor solid waste management, notably of construction debris, combined with a lack of paving, the solids load that is washed into sewers is much greater than is conventionally accounted for in the BS and ASTM standards.

However, the main problem with the adoption of Western standards relates to the cost implications related to the difference in design and construction standards between government projects and what communities can afford. Official specifications tend to be costly and unaffordable by the majority of communities who live in the ***katchi abadis*** in the cities of Pakistan.

Figure 1-5 illustrates the fact that increasing technical design specifications require a corresponding increase in capital investment and this results in a decrease in affordability. Subsequently, existing government endorsed specifications result in the design of systems that are unaffordable by the poorer communities.

Due to the need to reduce capital costs, many community-based initiatives construct sewerage systems that do not adhere to the official standards and specifications. This has led to the development of simpler and lower cost sewerage systems promoted by NGOs such as ASB in Faisalabad, as well as FAUP itself.

Figure 1-5 **Impact** of design specifications upon cost and affordability



These projects rarely use materials and construction methods that conform to government standards and, as a result government agencies are reluctant to officially adopt them and to accept responsibility for operation and maintenance.

Nevertheless, due to topographical constraints, community-based sewerage systems must often connect to WASA sewers and, because the connections are not formally recognised, communities receive no guaranteed level of service for operation and maintenance of the sewerage systems.

In this situation, WASA receives no revenue from these communities despite the fact they receive wastewater from unregistered household connections discharged into its sewers and incurring costs associated with the drainage and treatment of wastewater.

Therefore, in order to develop the legal backing for sewers constructed by private developers, NGOs, and community groups, there is a need to develop design criteria that is technically appropriate and satisfies the government line agencies requirements.

Wider replication is constrained by the lack of a formalised system for the adoption of sewers that satisfy the demands from government line agencies (WASA and PHED) for technically appropriate design specifications.

1.8 An alternative approach to the provision of sanitation

A workshop organised by the Water and Sanitation Programme and held in Faisalabad in 1998 was attended by a wide cross-section of stakeholders from both the governmental and nongovernmental sectors. The workshop participants identified the need to define `appropriate specifications' to clarify misinterpretations and the need for consistency in technical specification for the design of infrastructure.

There was also general consensus for the need for a testing and research programme to develop design specifications to meet the recommended appropriate standards. The workshop participants concluded that these should be pre-agreed and notified nationwide to avoid disputes after implementation, and also highlighted the need for training of NGOs/CBOs working in the sector to conform to requisite technical specifications

There is a general consensus for the need for officially ratified specifications for tertiary sewers that may be adopted by community infrastructure projects. There have also been a number of official statements in support of this argument (Box 1-2).

Box 1-2 Political support for appropriate technical standards

"Given the current financial position, if communities want to develop their own water and sanitation systems, they should be encouraged to do so. Similarly, if technical standards need to be relaxed to enable this, that too should be allowed without compromising system efficacy. "

K.B. Nasir -Technical Advisor, Department of Housing, Physical Planning and Environment, Government of Punjab

Proceedings of the First Round Table Discussion on Operational Issues in `One Million Plus' Cities of Punjab, Faisalabad, March 18-19, 1999.

The Proceedings of a workshop in Quetta in October 2000 organised by the Water and Sanitation Programme focused on financing, cost recovery, and subsidies for community sewerage. The recommendations from the workshop of particular include:

Communities should be solely responsible for household and lane level sanitation.
Services (hardware) in *katchi abadis,* middle class and elite neighbourhoods. At the lane level 25 percent of the available resources (from government, donor or program support) should be earmarked for providing subsidies to the poorest.

Operations and Maintenance of infrastructure at the household and lane level should also be the responsibility of communities.

Subsidy in the form of support to NGOs should be provided for activities, both at the household and lane level.

NGOs have a comparative advantage in delivery of technical assistance, social mobilisation, awareness raising, training and skill management (software).
NGOs not only have an important role to play before and during the installation of services but also in post-project monitoring and O&M training for community members.

Sanitation infrastructure at the neighbourhood and city level should be the responsibility of the government agencies alone.

Installation, operation and maintenance of trunk sewers is the government's responsibility. Municipal agencies should consult with communities and other stakeholders prior to installation of neighbourhood level infrastructure.

In both the short and long term, these recommendations may have considerable financial benefits to WASA and are relevant to future projects which adopt a FAUP type approach:

a) In the short term, this approach enables the government agencies responsible for the provision of sewerage to concentrate resources on the provision of the larger municipal infrastructure

b) In the long term, increasing the number of official house connections may increase the revenue of the service provider which subsequently increases the capacity of the agency responsible for sewerage and wastewater management to reinvest in secondary and primary services.

2.0 RESEARCH AND DEVELOPMENT

This chapter describes the research programme undertaken by FAUP in conjunction with WASA Faisalabad in the development of appropriate design criteria for tertiary sewerage systems. This involved a review of existing specifications and an evaluation of manufacturing and quality control procedures in the pipe casting yards. It also involved structural testing of pipes and an evaluation of the costs associated with production of concrete pipes and covers.

This research also evaluated the quality of construction and operational performance of the different components of tertiary sewage systems (household connections, haudi interceptor tanks, access chambers; and the lane sewers).

The fieldwork involved surveys of tertiary sewers to collect information to describe the construction of the sewers, the condition of access chambers and covers, and the extent of sedimentation and flow conditions in the sewers. The observations from the fieldwork influenced the design specifications (see Chapter 3) and were used to derive the operational and maintenance requirements as later described in Chapter 4.

2.1 The pipe manufacturing process

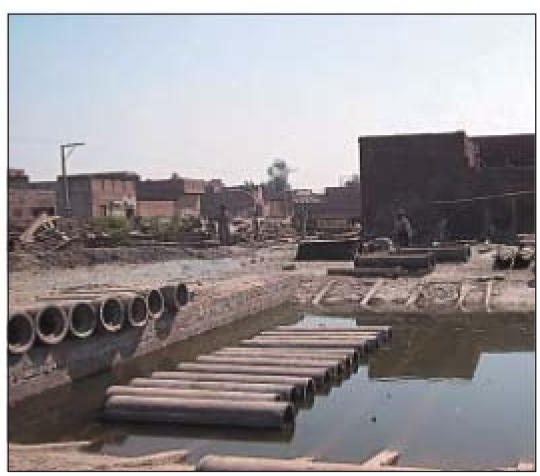
Both officially recognised and `informal' casting yards use essentially the same manufacturing technique, which involves `spinning' of concrete pipes using centrifugal force. Figures 2-1 to 2-4 illustrate the four main stages in the manufacture of concrete pipes.

Figure 2-1 Welding the reinforcement cage

Figure 2-2 Assembling the moulds

Figure 2-3 Placing concrete in spinning moulds

Figure 2-4 Curing the pipes



The pipe manufacturing process in the factories where WASA standard pipes are made was compared with observations from smaller factories where unregulated pipes are produced.

The main observations are described below

Concrete

In general, local pipe casting yards use a cement: aggregate: sand mix of 1:4:8 by weight. Although, reasonable attention is paid to measuring the sand and aggregate, little attention is paid to the measurement of water in the concrete mix. Cement and sand slurry was observed on the ground where the pipes were spun which suggested that the concrete had a very high
water:cement ratio.

Sand and Aggregate

The sand and aggregate used is generally similar but the size and quality of the aggregate varies considerably in different factories. In factories which use manufacture building products, better quality aggregate, consisting of granite and sharp sand, is used because the use of shale aggregate for structural items is generally not acceptable by contractors for construction purposes. Many of the smaller factories which make concrete slabs, irrigation and ornamental items and non-WASA pipes use low-quality brown shale aggregate.

Spinning

In order to provide a smooth finish to the inside surface of the pipes, which improves the quality of the pipes under visual inspection, a large quantity of cement is added towards the end of the spinning process. Up to 51b of cement is applied at this stage in the spinning process which results in a 0.1 in. layer on the inside of pipe wall. Depending upon the concrete mix, this can account for up to 20 -35% of the total cement used to make each pipe.

Reinforcement

The reinforcement of 9 in. pipes comprises of 4 longitudinal bars and 5 wire hoops. New steel is used for the reinforcement bars in the larger pipe factories, but in virtually all of the smaller yards, scrap steel is used instead of new steel.

Curing

The large factory where the WASA standard pipes are made has a large tank for curing the pipes. This is typical for the large factories, allowing better curing than in the small-scale factories which only have small tanks. The smaller unregulated pipe manufacturers pay little attention to ensuring that pipes are immersed in water and pipes are not left for a sufficient length of time to cure properly.

In general, the observations suggest that pipes made at small-scale factories are likely to be of poor quality, low strength and low durability, because of poor quality materials and production methods.

Observations of production practices at the smaller pipe factories raised a number of concerns. Some of the pipes at these factories had uneven wall thickness and/or honeycombing. The use of poor quality materials and methods used in construction will probably have a substantially shortened service life.

However, the observations in the WASA pipe manufacturing yard also indicated deficiencies and hence the normal production of pipes that are claimed to be of WASA standard are likely to be low strength, with low durability concrete.

In summary, the observations of pipe manufacturing indicated that concrete strengths are probably lower than claimed by the manufacturers, due to:

i. inaccurate gauging and measuring of materials, using irregular sized containers of unknown volume,

ii. excessive use of water, iii. use of less cement than claimed,

iv. loss of cement during spinning (contained in excess water),

v. use of poor quality aggregates (dusty, low strength, poor grading brown shale). Only two factories were observed to use granite.

vi. inadequate curing of the finished products (small factories only).

vii. use of low quality reinforcement (recycled wire and steel in small factory pipes).

2.2 Testing of pipes strengths

As a result of the observations described above and the requests from WASA to investigate the structural strengths of pipes adopted by FAUP. A pipe testing programme of was designed which involved the structural testing of a range of pipes of varying specifications to evaluate their strength in relation to cost.

Making pipes with concrete less than 1:4:8 mix was not considered because of the low strength of these mixes. Various reinforcement arrangements were considered, to improve crushing strength, and minimise the effects of poor compacting of backfill.

Six combinations of concrete and reinforcement were tested. The structural specifications associated with these pipes (A-F) are detailed in Table 2-1. These pipes were made under supervision to ensure their quality and the production was observed to ensure proper measuring of the sand, aggregate and water and the materials were measured using containers of known volume.

The aggregate used for the pipes comprised 2 parts 1/2 in. granite and one part 1/a in. shale to provide a dense, well-graded concrete. The water:cement ratio was limited to 0.72 for 1:3:6 concrete, and 0.67 for 1:2:4 concrete. These are the maximum ratios permitted by the WASA specification for concrete.

The water:cement ratio was controlled in order to provide a dry, workable mix and to minimise cement loss during spinning. The spinning and curing of the pipes was also monitored. Each pipe and cover was cured in water for at least seven days, checked by random visits. The reinforcement cages for the pipes were welded, although only tying was required. This was because the factory felt they were easier to make by welding.

Three samples of each pipe were tested to obtain more representative results and the strengths of these pipes were compared with pipes purchased from manufacturing yards officially ratified by WASA and those purchased from informal smallscale pipe casting yards where there were no certified quality control procedures. The pipes were selected at random to ensure that they were representative of normal production.

The tests to compare the structural strength of the concrete pipes were:

Pipe crushing strengths

Compressive strength of concrete

Pipe crushing strengths

Three-edge bearing tests were carried out to determine the pipe crushing strengths (see Figure 2-5). Readings were taken when the first hairline crack, then second hairline crack was observed, and when the main crack was observed to be 1/12 in. (2 mm) wide (see Figure 2-6). The pipes were tested to the point of collapse (see Figure 2-7).

Figure 2-5 Three-edge bearing tests

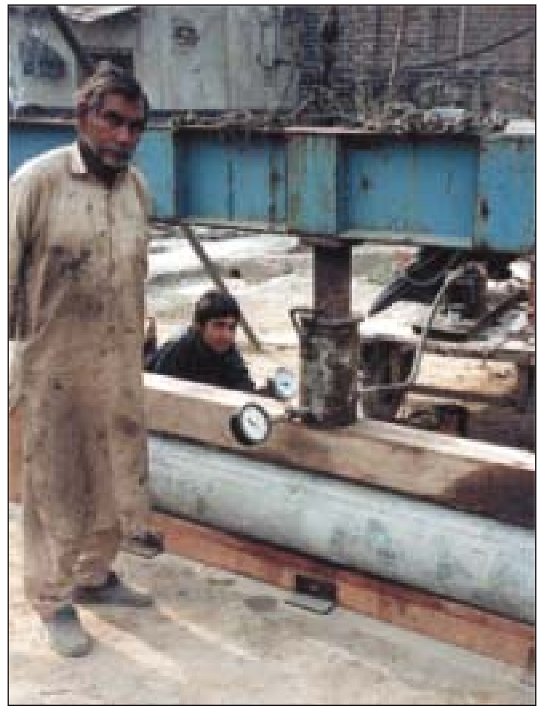


Figure 2-6 Loading of pipe to achieve 2mm wide crack (secondary gauge)

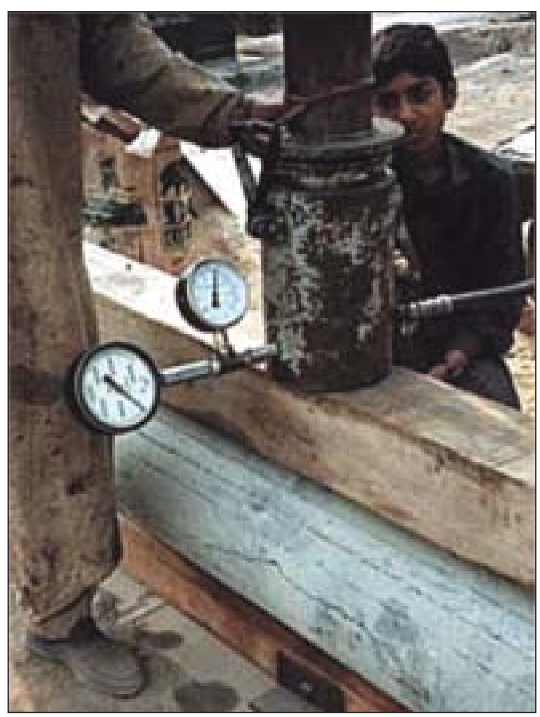


Figure 2 7 Substantial deformation of pipe without collapse

Compressive strength of concrete

The Schmidt hammer test is a non-destructive test that provides a measure of the compressive strength of the concrete. The Schmidt hammer is applied to the pipe to obtain a reading in N MM -2.

Figure 2-8 Schmidt hammer test

2.2.1 Results of pipe testing

The concrete of the `controlled' pipes appeared to have little honeycombing and was denser than the `normal-production' pipes. These pipes had a slight ringing sound when struck with a small hammer in comparison with the pipes produced by both the unregulated and regulated yards which emitted a dull `thud' suggesting a fresh or low density concrete.

In the pipes where the spacing of the reinforcement hoop steel was wide, some of the large aggregate was observed to work its way behind the longitudinal bars, forcing them out of the inside face of the pipe during spinning. On several pipes the ends of the longitudinal bars were visible, on some pipes the hoop steel was also visible. In both cases this was irrespective of the concrete mix.

Analysis of the factory pipes showed concrete mixes between 1:4:18 and 1:8:13, and poorly graded 1/a in. brown shale aggregate. Concrete porosity was only slightly higher in several of the factory pipes, indicating that their low strength is due to low strength concrete and not porosity. Due to the high water:cement ratios, it was concluded that excessive water is removed during spinning along with some of the cement, which increases the density of the concrete but reduces the strength.

The normal procedure for mixing concrete was watched using a controlled process to ensure that any changes were made only where necessary. While there was reasonable attention to measuring the sand and aggregate, there was no measuring of the water. It was therefore necessary to abandon the first batch of 1:4:8 concrete. However, as there is no water:cement ratio in the WASA specification for 1:4:8 concrete, it was difficult to control the condition of this mix. There were no problems with the other mixes.

Some fine material was lost through the joints of the moulds on a few pipes. The outer surfaces of the pipes were clean and generally light in colour. There was no sign of staining by mould oil.

It was difficult to provide a reasonable finish to the inside of the pipes without adding large quantities of cement, towards the end of the spinning. This particularly affected the 1:4:8 pipes. As much as 3 kg of cement was added to each pipe to ensure a smooth internal finish. The finished thickness of the cement was approximately 1/8 in. (3 mm) over the whole of the pipe.

Table 2-1 Summary of the results from the pipe testing

Pipe Type	Concrete	Reinforcement		Three Edge bearing test			Schmidt Hammer test
	Cement : Sand : Aggregate ratio	No. of 3/16 in. dia. longitudinal bars	No. of 1/8 in. dia. Bars	Hairline (kN/m)		2mm wide crack (kN/m)	
				Main	Secondary		N / mm^2
A	1 : 4 : 8	8	7 circ. hoops	13.3	-	-	19.2
B	1 : 4 : 8	6	13 circ. hoops	10.8	10.1	15.5	21.8
C	1 : 3 : 6	6	13 circ. hoops	11.0	13.1	15.7	24.7
D	1 : 3 : 6	6	9 circ. hoops	15.0	12.8	15.5	24.6
E	1 : 2 : 4	6	9 circ. hoops	15.8	13.9	15.5	25.4
F	1 : 3 : 6	6	spiral at 6 in. spacing	13.0	12.8	13.9	27.2
WASA	1 : 1 : 3	Total weight of reinforcement 14 lbs per 8 ft. pipe		15.0	12.0	20.4	25.2
Unregulated	1 : 2 : 4	4	5 - 7	0	1.1	1.1	0

As shown in Table 2-1, None of the sample pipes from the pipe manufacturing yards achieved the 25 kN/m minimum crushing strength required by BS 5911. The pipes made under controlled conditions using 1:3:6 and 1:2:4 concrete were approximately 25 % and 35 % stronger than the pipes from the unregulated manufacturing yards.

The tests showed an increase in strength in the range 13-27% for pipes manufactured using a 1:3:6 mix over those using a 1:4:8 mix.. This may be achieved for a 3 -7% increase in cost, depending on the manufacturer. Increasing the cement ratio to 1:2:4 provided a 5% increase in crushing strength over 1:3:6 concrete, and 35% over 1:4:8, for 8 -10% and 11 -17 % increases in cost respectively, depending on the manufacturer.

The further increase in strength obtained by using a 1:2:4 mix was not so significant, implying that the increase in strength for a 1:2:4 mix was lower than might be expected. The results suggest that the relatively low increase in strength for a 1:2:4 mix could be explained by voids which were observed in the concrete when it was opened for inspection.

Increasing the amount of reinforcement only resulted in a relatively small increase in strength.

The amount of hoop steel had only a small effect on the load at which the first crack appeared. The use of vertical hoops may be preferable to spiral steel. Where the hoops are wire, little or no extra load is required to achieve collapse. Where they are of steel it is necessary to increase the load quite substantially to achieve further deformation and collapse of the pipe.

All the pipes manufactured under controlled conditions performed better than comparable commercial pipes, because of the materials and methods used. A strong correlation between the strength of the concrete and the load at which the first crack appears in the pipe was observed.

If the steel in an FAUP pipe were replaced by concrete it would be possible to increase its wall thickness to just over 2 in.. It is probable that strength would increase similarly, however weight would probably be prohibitive and new moulds would also be required.

Table 2–1 Estimated cost of pipe manufacture

	WASA standard		FAUP (Pipes A-F)		Unregulated commercial Pipes	
	Rs.		Rs.		Rs.	
Cement	40	14%	37	17%	25	20%
Sand		2%	5	2%	4	3%
Aggregate	12	4%	10	5%	8	6%
Sub - total Concrete	57	21%	52	25%	37	29%
Reinforcement	140	51%	100	47%	40	31%
Sub - total	197	71%	152	72%	77	61%
Cost of materials	25		19		10	
Rs. Ft.$^{-1}$	80	29%	60	28%	50	39%
Labour / Profit	277		212		127	
Total						
Rs. Ft.$^{-1}$	35		27		16	

2.3 Cost implications

Table 2-2 shows the estimated costs of manufacture of different types of concrete pipe. The cost of manufacture of the FAUP pipes (A-F) ranged from approximately Rs. 23 to Rs. 27 depending upon the amount of cement and reinforcement which are the two factors that contribute the most to the cost of the pipe.

The costs of labour and profit are estimates and are used to provide a comparative analysis of the relative labour and profit related costs of the different pipes. It is apparent that the relative costs associated with labour and profit increase as the material costs decrease.

Steel and cement are the most expensive materials. Using more of these materials has a greater effect on cost. The cement used to make concrete pipes was found to be between 20-30% of the total material cost. The cost of the steel used for reinforcement approximately 30 % of the total material costs for small factory pipes, and over 50% for the pipes produced to WASA standard.

The cost of cement is prone to variations according to the market prices. During the course of the research, the cost of cement was observed to increase by as much as 25 %, but the price of pipes did not rise in relation to the increase in cement. This implies that less cement was being used and if sewer pipes are to meet the requirements of BS5911, pipe prices will have to rise accordingly or labour, overheads, or profit will have to be reduced.

Some changes have little impact on cost but may have significant impacts on the resultant pipe strengths. For example, the use of granite aggregate instead of shale costs about Rs. 2.5 more per pipe, and sharp sand only about Rs. 1 per pipe. Other changes have no impact on cost but may result in significant improvements in strength. These relate to quality control of the water:cement ratio and improved curing in manufacturing

The increase in cost for the 1:3:6 and the 1:2:4 pipes was calculated to be approximately 10% and 20% respectively, which is considerably less than the respective increases in concrete strength of up to 30 -40%. This is especially relevant if the increased concrete strength means that a less reinforcement can be used.

This cement which is added at the end of the spinning to the inside of the pipe to improve the surfacing of the pipe adds considerably to the cost of production, but has little benefit to the resultant structural integrity or durability of the pipe. It is recommended that this cement is used for the production of a higher grade concrete.

In conclusion, the results from the pipe testing indicate that it is possible to produce a pipe that is appropriate for tertiary sewers at a lower cost than those available from existing WASA approved pipe casting yards. The use of an improved concrete mix with more cement can result in significant increases in concrete strength.

2.4 Manholes and access chambers

Tertiary sewer access chambers are generally circular (internal diameter 22 in.) and constructed of concrete cast in situ. The manholes were constructed without any benching and flow through the chambers was generally poor, especially due to the accumulation of solids.

The structural condition of the chambers surveyed was generally good, with no significant corrosion or decay of the concrete. However, bricks are sometimes laid on top the concrete in order to raise the manhole cover to the surface level of the road. Observed problems relate to the quality of the brickwork near the surface and in some cases, bricks fall into the base of the chamber.

Manhole and access chamber covers are critical weak spots in the sewerage systems for the following reasons

a) they are subject to the most impacts from surface loads
b) they may be removed for drainage of surface water or stolen for the steel reinforcement bars
c) once broken or missing, solids can easily enter and block the sewer.

A combination of leverage and lifting is necessary for lifting of access chamber covers. They are removed using leverage and replaced using hooks or handles built into the manhole cover. These often protrude from the surface and are exposed to corrosion and are liable to damage especially by traffic. Where there are no hooks or handles, replacement proves to be difficult and breakages can occur when trying to replace the cover into position.

Breakages of manhole covers are related to the poor quality of materials or construction rather than a deficiency in the design (Figure 2-9). The lack of a surround or collar often proved to be a common design defect (Figure 2-10).

Recent evidence from OPP documented by Zaidi (2001) also indicated broken manhole covers and blocked sewers. These were observed to be a small percentage of the total sewers laid, but the report suggests that there might be a need to modify the manhole cover design and manufacture to improve the structural integrity.

Other problems are related to ponding of surface water and as a result, many access covers are removed or broken deliberately to allow stormwater to drain into the sewerage system. Sometimes manholes covers are modified to enable drainage of standing surface runoff and wastewater (see Figure 2-11).

Figure 2-9 Structural decay of manhole cover

Figure 2-10 Structural problems caused by lack of cover surround

Figure 2-11 Modifications to the manhole cover to drain surface water

2.4.1 Testing of chamber covers

The design was developed based upon the cover used by FAUP as well as NGOs such as OPP and ASB in Faisalabad. Based upon the observations described above in Section 2.4, the access chambers cover was modified and tested.

Figures 2-12 to 2-15 show the stages in the production of pre-cast manhole covers. The covers were made in a factory which specialises in the manufacture of building products. Sharp sand and pure granite was only used for the covers.

The covers were cast upside-down and hand compacted. Care was taken to avoid trapping of air between the mould and the concrete.

A series of tests were carried out on the access chamber covers used by FAUP and these were compared with the WASA standard manhole covers which are 7 in. thick and prefabricated using a concrete mix 1:11h :3. The WASA covers are heavily reinforced using steel reinforcement bars.

As a further comparison, some tests were carried out on manhole covers supplied by a manufacturer in Karachi which fabricates ferrous fibre reinforced covers. The manufacturer claims that these are cheaper, stronger, and more durable than conventional steel reinforced concrete manhole covers

Ring bearing tests were carried out to test the structural capacity of the covers (Figure 2-16) and Schmidt hammer tests were also carried out to test the compressive strength of the concrete used to make the covers (Figure 2-17).

Table 2-3 shows the results of the manhole cover tests from the Schmidt Hammer Test (compressive strength) and the point load test (bearing capacity). The quality of the concrete for the fibre reinforced covers was high in comparison to the FAUP design, but the bearing capacity was observed to be lower. The FAUP covers were considerably less resistant to the point load test than the WASA covers which was to be expected due to fact that they are 50% less thick.

Figure 2-12 Mould for casting access chamber Covers

Figure 2-13 Arrangement of the cover reinforcement bars

Figure 2-14 Compaction of the concrete mix in the cover mould

Figure 2-15 Access cover before curing

Figure 2-16 Bearing test rig for covers

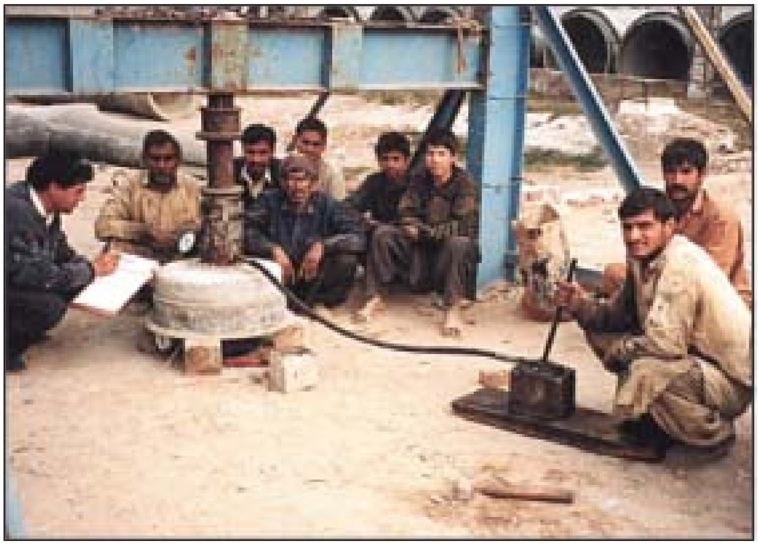


Figure 2-16 Schmidt hamer test

Table 2-3 Manhole cover testing

	Schmidt Hammer Test Compressive strength				Point load test Bearing capacity	
FAUP design 3 in. thick / concrete mix 1:2:4	**I**	**II**	**III**	**Mean**	**Initial Crack**	**Crack 2 mm thick**
	N mm^{-2}	N mm^{-2}	N mm^{-2}	N mm^{-2}	kN	kN
F-1	25.5	24	25	25	64	79
F-2	24.5	23	24	24	64	85
F-3	24	20.5	21.0	22	53	69
Average	24.7	22.5	23.3	23.7	60	78
Fibre reinforced slab (1.5 in. thick)						
K – 1	27	26.5	28	27	21	25
K – 2	29	28.5	27.5	28	19	23
Average	28.0	27.5	27.8	27.5	20	24
WASA - 7 in. thick / concrete mix 1: 1.5 :3						
W – 1	34	32	36	34	127	143
W – 2	30	35	33	34	132	143
W – 3	31.5	35	32	33	122	138
Average	31.8	34.0	33.7	33.3	127	141

3.0 DESIGN AND CONSTRUCTION

The design standards and construction specifications for tertiary sewerage systems are based upon an evaluation of construction practices and operational performance and the research and development described in the previous chapter.

The recommended standards for sewer pipes focus upon diameters, gradients, and depth of cover, and the specifications focus upon pipe manufacturing and construction of pipelines. Standards and specifications for design and construction of access chambers and household connections to the tertiary sewerage system are also described.

The proposed design criteria for tertiary sewerage systems may be applied to lanes which are 300-360 ft. long and the width of the road carriageway is approximately 15 ft.. A lane sewer will generally serve approximately 30 households with a population of about 200.

Figure 3-1 illustrates a lane in which a tertiary sewer may be laid and Figure 3-2 shows a typical sewer layout, indicating the lanes in which the design specifications described in this chapter may be adopted.

3.1 Design of sewerage systems

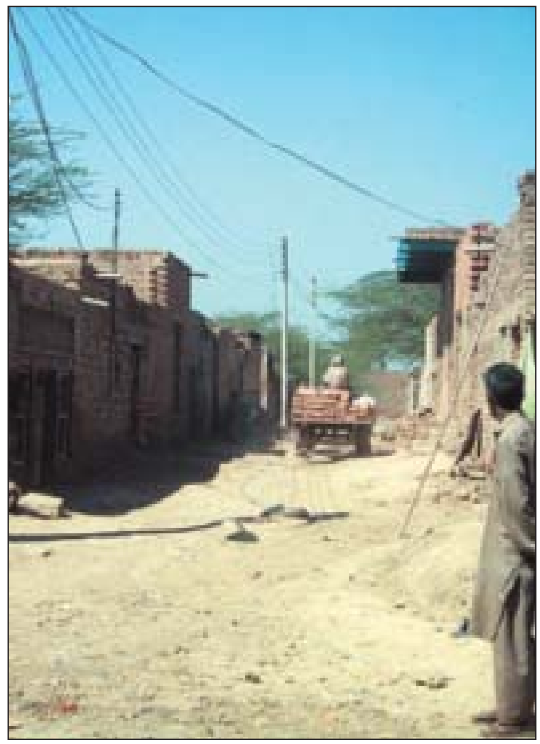
From a technical perspective, the basis for adopting the proposed specifications is that, in the narrow lanes in residential areas, the imposed surface loads on buried pipelines from traffic are lower than in wider, busier streets. In these situations, it is proposed that sewers may be laid to lower depths than those that are currently specified by the existing standards.

The existing designs for brick manholes are unsuitable for sewers which are laid to less than 5 ft. deep. Alternative designs are therefore required to facilitate cleaning and for house connections in tertiary sewerage systems.

In conventional design procedures, the selfcleansing flow velocity is dependent upon the quantity of wastewater discharged into the sewer and the diameter, slope and roughness of the pipe. However, evidence from the fieldwork carried out by FAUP shows that in practice the capacity of the pipe is governed by:

- the extent of deposited sediment
- blockages in the sewers
- the operation of downstream pumping which drowns the outfall of the sewers and reduces the hydraulic head.

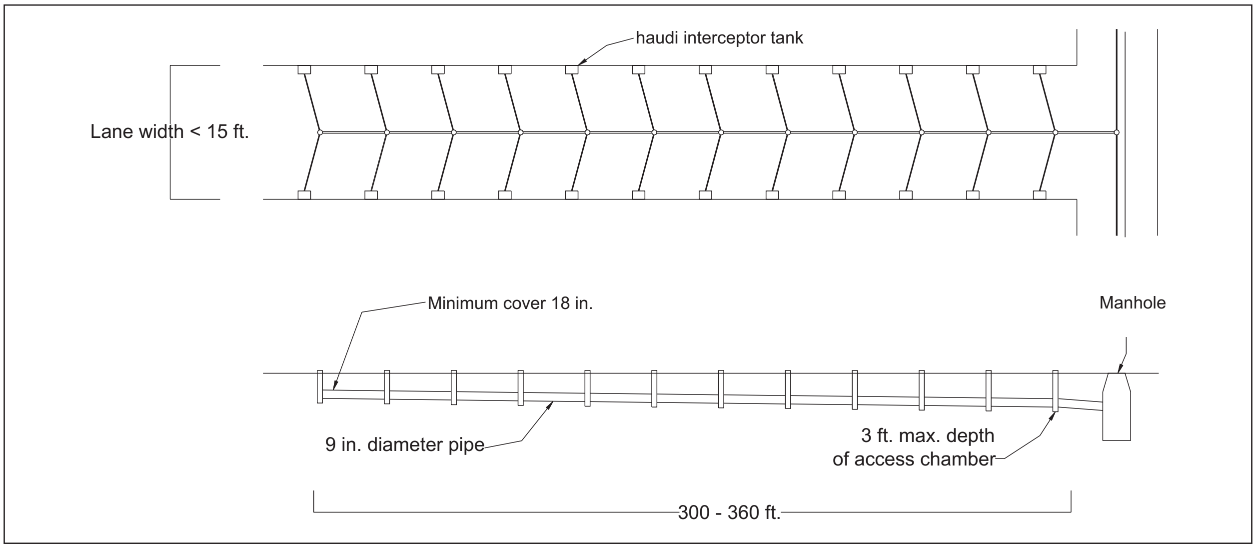
Figure 3-1 Typical lane suitable for a tertiary sewer



A combination of these factors means that in practice, self-cleansing velocities are rarely feasible and, due to the flat topography and the depths of the secondary sewerage system (to which tertiary sewers connect), pipe gradients defined by conventional design criteria are difficult to achieve.

As a result, sediment deposits invariably collect in tertiary sewers, reducing hydraulic capacity and increasing the likelihood of blockage by other solid wastes. In addition, the high solids loading means that the maximum velocities are insufficient to transport and erode deposited sediment.

Figure 3-2 Plan and longitudinal cross section of tertiary sewer



The sewerage systems should be designed for the drainage of foul wastewater from residential properties during dry weather flow (DWF) conditions. In Pakistan, where climatic conditions and seasonal variations in rainfall are significant, it is not recommended that sewers are sized for flood alleviation caused by rainfall of high intensity or long duration. The inclusion of stormwater in the design flow equations increases pipe diameters and dramatically increases the cost of the system.

In conventional design, sewers are often designed for drainage of floodwater. Sewers are designed either as combined sewers or separate systems. However, separation of surface water from foul wastewater drainage systems is virtually impossible to achieve in practice.

The entry of solid waste into the sewerage system poses a serious problem which compromises the effective operation for drainage. This is a particular problem in areas where manholes are broken or removed intentionally to drain surface water.

In order to mitigate these problems, sewers should be designed to i) minimise the entry of sediments into the sewers and ii) make cleaning of them as easy as possible. Solids traps and interceptor tanks on household connections are therefore an integral component of the recommended design for tertiary sewerage systems. The design of these is described in detail in section 3 7.

-

3.1.1 Minimum sewer diameter

The Water and Sewerage Agencies in Pakistan specify a minimum sewer diameter of 9 in. Although, there are examples where 6 in. pipes have been used for construction of tertiary sewers, there is a prevailing attitude that 6 in. pipes are unsuitable and these are not officially accepted by government engineers
.

Nevertheless, even though recommendations for reducing the minimum diameter to 6 in. are not generally accepted, it is worth discussing the factors that influence the minimum pipe diameter.

Figure 3-3 Forces on 6 in. and 9 in. Pipes unsupported by backfill

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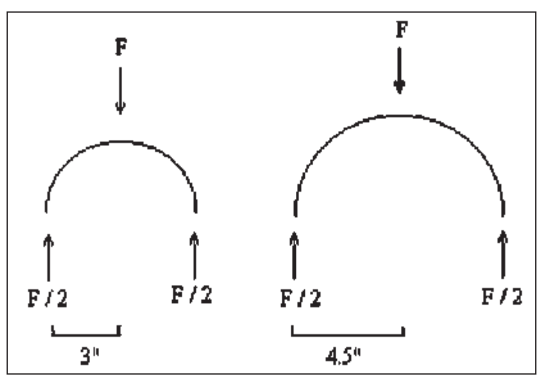


Smaller pipes are also stronger due to the reduced bending moment exerted by imposed load. Figure 3-3 shows the forces acting upon pipes where unsupported by backfill. The maximum bending moment (force x distance) acting on a 9 in. diameter pipe is proportional to the radius and is therefore 1.5 greater than that acting on the smaller 6 in. pipe.

Due to the reduced volume of concrete and steel for reinforcement, smaller diameter pipes are also cheaper. This will depend upon the quality of the pipes that are being compared and many small diameter pipes produced by unregulated pipe casting yards are very cheap due to their inferior quality. However, the market rate for a WASA standard 6 in. pipe costs Rs. 240 whereas a 9 in. pipe of the same length costs Rs. 360. The difference in the cost between 9 in. and 6 in. diameter sewers is approximately 25%-30%.

From a hydraulic perspective, due to the reduced cross-sectional area, the flow velocities in 6 in. pipes are greater than those in 9 in. pipes at the same discharge. Smaller pipes therefore provide more favourable flow conditions to achieve self-cleaning velocities. Readers should refer to the Indian Practical Civil Engineer's Handbook (Khanna, 1992) which states that increasing pipe diameter does not improve hydraulic performance to convey solids.

Although smaller diameter sewers provide an improved hydraulic performance, there is a reluctance to adopt a reduced minimum pipe diameter of 6 in.. This is based upon the practical limitations of cleaning smaller diameter sewers and the understanding that blockages are bound to occur and larger pipe diameters enable the system to function even when partially blocked.

Practical experience also suggests that 6 in. sewers are more prone to blockages. In some parts of Faisalabad, WASA has received numerous complaints about recurring problems related to sewer blockages and overflow of sewage. These problems have been attributed to the 6 in. diameter pipes and as a result WASA has replaced these pipes with 9 in. diameter pipes.

In conclusion, although there is a strong theoretical basis for adopting 6 in. as the minimum permissible diameter for tertiary sewers, the minimum recommended sewer diameter should remain at 9 in. This standard should remain until there is further evidence to demonstrate that smaller diameter pipes are practically feasible and procedures for cleaning sewers are improved.

3.1.2 Minimum -rah diem

According to Punjab PHED, the minimum gradient for sewer pipes is based upon the attainment of a self-cleansing velocity of 21/a ft sec -1 at design flow. However, in tertiary sewers, this invariably means that a steeper gradient than is practically feasible at the head of a sewer is required.

Therefore, in practice, the gradient of the sewer is usually determined by the level of the secondary sewer to which it is connected, the local ground levels and the need to achieve a minimum depth of cover to the pipe.

The minimum recommended design slopes for tertiary sewerage systems are described on Table 3-1. Where interceptor tanks are incorporated as an integral component of the design, the minimum slope for a 9 in. diameter sewers is 1 in 400 which is equivalent to a fall of 3 in. per 100 ft. length of sewer.

However, where possible the sewer should be laid at a steeper gradient of 1 in 300 (4 in. per 100 ft.) provided that the minimum recommended cover is maintained at all locations (see Section 3.2.1). However, in some situations, in order to achieve self-cleansing velocities, it may be advisable to use lower cover depths (with protective concrete slabs to protect the sewer from surface loads).

Table 3-1 Recommended minimum gradients for 9 in. tertiary sewers

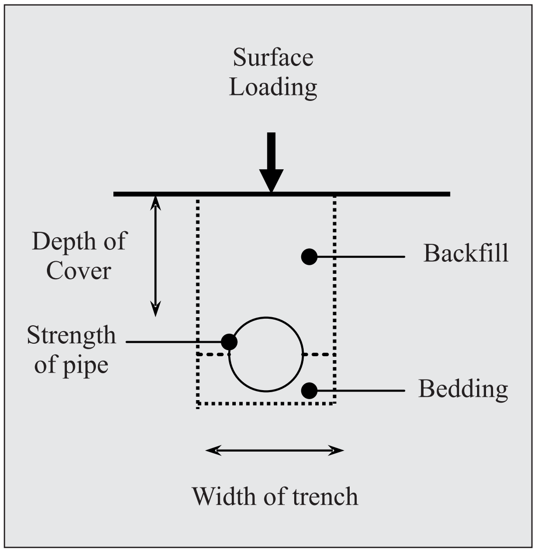
		Slope	Fall in 100 ft.	Tolerance
No haudi inceptor tanks	Recommended	1:150	8 in.	+/- 1 in.
	Minimum	1:200	6 in.	+/- 1 in.
Haudi inceptor tanks	Recommended	1:300	4 in.	+/- 0.5 in.
	Minimum	1:400	3 in.	+/- 0.5 in.

3.2 Structural design of sewer pipes

The structural integrity of a buried pipe is one of the most important factors in the design of sewerage systems because pipe fractures and structural collapses are expensive to rectify.

Figure 3-4 and Box 3-1 describe the factors that influence the structural integrity of a buried pipeline. These factors are considered in relation to the design specifications and construction of tertiary sewerage systems.

Figure 3-4 Factors influencing the structural integrity of a buried pipe

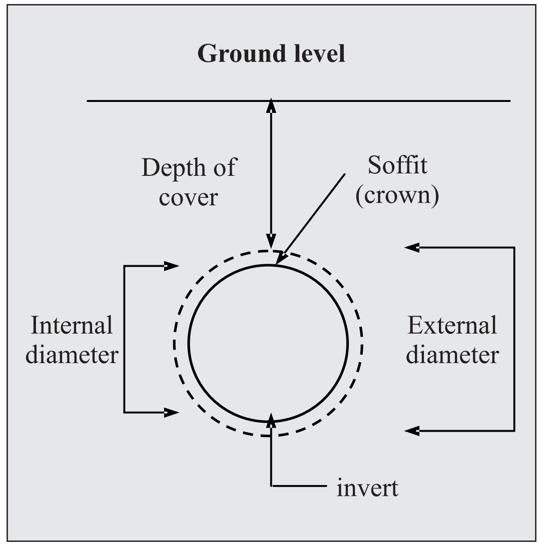


Box 3-1 Factors influencing the structural integrity of a buried pipe

1) **Surface loading**
Traffic and other imposed loads from the surface
2) **Strength of pipe**
Combined strength of concrete and reinforcement
3) **Depth of cover**
Depth from ground level to crown of pipe
4) **Backfill**
Type of backfill material and compaction
5) **Bedding**
Type and level of bedding material
6) **Width of trench**

Figure 3-5 defines the dimensions of sewers in terms of the depth of cover, diameter of pipe and invert level which define the specifications and are used for pipe laying during construction.

Figure 3-5 Definition of sewer dimensions



3.2.1 Depth of cover

The depth of cover relates to the surface loadings caused by traffic loads which are governed by the width of a street, which limits the size of the vehicles that can use it. In the narrowest lanes, the heaviest imposed load is a horse cart loaded with bricks. In wider streets it is a single axle trailer, also loaded with bricks.

The study identified the maximum loads expected in different type of street and, in conjunction with the in-situ test results, these were used to determine safe loads for the pipes and make recommendations for the minimum depth of cover.

In some locations, tertiary sewers have been constructed at cover depths of 11/2 ft. which have not resulted in any problems provided sufficient attention is given to bedding, backfilling and surfacing. This experience suggests that low cover depths are feasible in locations where surface loads are known to be low. However, it is more cost effective to lay a pipe at a slightly greater depth and use selected soil as the backfill material, rather than granular material if gradients allow.

Recommended minimum covers for other streets are shown in Table 3-2. It is recommended that cover should be no less than 18 in. for tertiary sewers in lanes where the road carriageway is less than 15 ft. Wide.

Table 3-2 Recommended minimum cover depths for concrete pipes

Street width	Vehicle loads	Minimum cover
up to 15 ft.	Motorcycles, small cars, light carts	18 in.
15 - 20 ft.	large cars, vans, animal carts	24 in.
> 20 ft.	Large trucks	30 in.

In some situations, it will not be possible to adhere to the recommended minimum cover. This will normally be due to the local topography and the depth of the secondary sewer, or the presence of other buried services such as gas mains or water supply pipes. It is advisable to lay sewers below water mains to reduce the potential for contamination of the water supply.

In these situations where pipes have to be laid closer to ground level, they should be bedded in granular material, and, if cover depths are less than 12 in., a reinforced concrete slab should be placed above the pipe. The slab should be greater than the width of the trench and 21/2 in. thick. It should be constructed of 1:3:6 concrete and reinforced using 7/16 in. steel bars at 3 in. spacing.

3.3 Recommendations for making concrete Pipes

The observations from the pipe manufacturing procedures described in Chapter 2 show that greater attention should be paid to improving quality control procedures in the measurement and storage of materials.

In particular, clear demarcation between different aggregates and provision of hard slab surfaces so that materials cannot become mixed with earth from the ground is recommended. All the materials, including water, should be carefully measured (Figure 3-6).

It is recommended that the quantities required should be based on a 50 kg (112 lb) bag of cement. A box 20 in. square and 161/4 in. deep can be used to measure 3.85 ft3 of sand and a horizontal line marked 143/4 in. above the base may be used to measure 3.75 ft3 of sand for 1:2:4 concrete mix (see Table 3-3). All measures should be level measures.

Figure 3-6 Measuring aggregate using a standard sized container

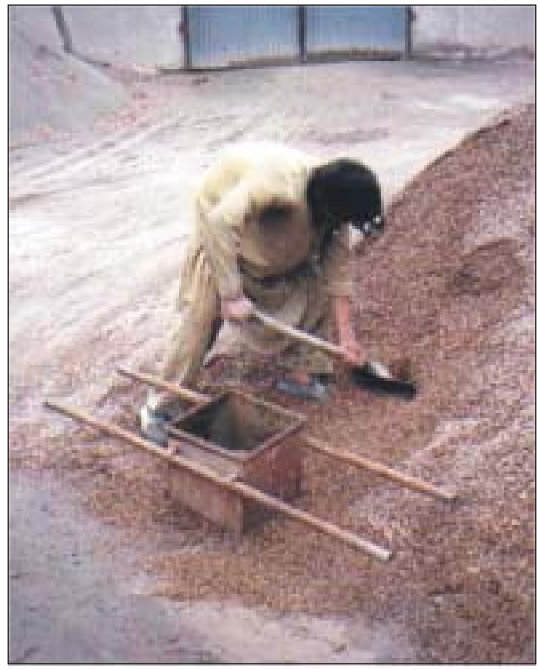


Figure 3-7 Measuring cement using a standard sized container

Table 3-3 Cement: sand: aggregate ratios for concrete pipes

Concrete Mix	Cement (ft^3)	Sand (ft^3)	Aggregate (ft^3)
1:3:6	1.285	3.85	7.7
1:2:4	1.875	3.75	7.5

3.3.1 Concrete

The minimum ratio of cement: sand: aggregate for sewer pipes and access chambers is 1:3:6 by weight. However, a ratio of 1:2:4 is recommended for structural cement to withstand the impact of imposed loads.

This may be achieved at little extra cost by reducing the amount of concrete used to line the inner surface of the pipe. Up to 60% of the cement used to line the pipes should be added to the concrete instead. The resultant mix is more workable and the strength of the pipe will increase. The amount of cement required for a smooth finish to the pipe will also be less. The result should be a better quality pipe for about the same cost.

3.3.2 Aggregate and sand

Shale is not a good aggregate as it is less strong than granite, smoother, and breaks more easily. It also does not bond well to cement, especially if it is dusty. The use of brown shale should therefore therefore be discouraged.

The use of fine shale is acceptable if the coarse aggregate is granite, which should be used wherever possible. Aggregate might therefore consist of a mixture of granite chips and black shale. Concrete aggregate should be evenly graded, up to 3/8 in. A well-graded even aggregate will make the concrete denser and more workable. Grading can be achieved by adding about 1/3 fine aggregate to 2/3 coarse aggregate.

Recommendations for aggregate include:

- aggregate contains a good mix of large and small stones, most of which is granite, or perhaps black shale.
- aggregate is clean and free from dust.
- sand should be a mixture of fine and coarse sand.
- sand and aggregate are measured using a gauging box of uniform size and shape.

3.3.3 Water: Cement ratio

Using more water than recommended results in the loss of water during the spinning process, along with cement and sand. Fine drops of excess water can also be left in the concrete after spinning. As the concrete dries the water dries out too, leaving small bubbles of air in the concrete and making it porous, less dense and weaker than it should be.
Using less water makes the mix less workable but much stronger. Concrete that has been made with too much water is often soft, dusty and can easily be worn away. It also makes a dull `thud' if hit with a hammer rather than a firmer, ringing sort of sound.

Careful control of the amount of water used to make the concrete will improve its strength. Recommended water cement ratios are described in Table 3-4. For 1:3:6 concrete the maximum recommended water cement ratio is 0.65, which equates to 35 litres (7.5 gallons) for every 50kg (1 bag of cement), and for 1:2:4 concrete the ratio is reduces to 0.60 which equates to 30 litres (6.8 gallons) per bag.

Table 3-4 Recommended water-cement ratios

Concrete Mix	Water: Cement ratio
1:3:6	0.65
1:2:4	0.6

The water should be added to the concrete mix using a 1 gallon or 5 litre container. This will make it easier to measure of the quantity of water used. Only part of the water should be added at the beginning of mixing (60% maximum).

The remaining water should be added in small quantities as mixing continues. The mix should remain `dry'. A rough indicator is that it should be possible to mould the fresh concrete into a ball in one hand and it should not be possible to squeeze water out of the mix. If the sand and aggregate is wet from rain, less water may be required than normal.

3.3.4 Reinforcement

It is better to have a pipe made of good quality concrete with hoop steel than one made of poor quality concrete with a lot of hoop wire. The steel should be new, not scrap or recycled. Reinforcement bars should be bound together using strong binding wire.

Providing sufficient hoop steel is more important than providing a large number of longitudinal bars. There should be 6 longitudinal bars. Hoop steel should be used rather than hoop wire, at about 9 in. centres. This provides better control of the longitudinal bars during casting and increased strength to the pipe, even if the quality of the concrete is poor.

3.3.5 Spinning

The objective of spinning is to compact the concrete in order to increase the density. The strength of concrete can be reduced by 30% simply by the presence of 5% voids due to poor compaction.

3.3.6 Curing of Concrete Pipes

Curing involves keeping the concrete moist and at a suitable temperature to enable the concrete to harden. To ensure that concrete reaches the required strength, it important to cure concrete correctly. This is because cement requires water to gain strength, and the process of hardening takes a number of days.

Concrete that has not been cured properly is very similar to concrete that has been made with too much water, i.e. soft, dusty and easily worn away and is of low structural integrity. Concrete which has been made with 10% less cement and has been cured properly will be stronger than a concrete that has not been cured properly.

The recommended curing process should involve immersion in water for at least 5 days after casting followed by a further 7 days where the pipes are kept damp using cloth matting or hessian which is sprayed with water.

Surfaces exposed to the sun and drying winds are of particular concern in pipe manufacture as evaporation of moisture results in rapid drying and cracking of the concrete.

Pipes manufactured in casting yards which do not have sufficient pond space for immersing pipes should not be used for the construction of sewerage systems. The water tank needs to be large enough to contain several days production. In many cases, this may require an increase in the surface area of curing ponds.

Box 3-2 Good and bad signs in malting concrete pipes

Good signs

- The yard is reasonably clean and tidy.
- The concrete looks quite dry after it has been mixed. It can be shaped into a ball in the hand, but water cannot be squeezed out of it.
- There is little or no water lying around the area where the pipes are spun.
- There are no lines or different colours on the surface of the pipe that show where the reinforcement is.
- When the pipe is hit with a metal object it makes a slight ringing sound.
- It is not possible to dent or rub away the surfaces of the pipe using a hard object.
- The pipe is straight and of even thickness throughout its length.
- There are no cracks in the pipe and the reinforcement is not showing, either inside or out.

Bad signs

- There is water lying around the place where the pipe is spun.
- The pipe sounds dull when hit with a metal object.
- The surface of the concrete is black indicating that the concrete is porous and has absorbed the oil that was on the mould.
- The surface of the concrete is soft and or dusty.
- Only small size stones can be seen in the pipe, or in the yard.

3.4 Recommendations for laying sewers

Without due care attention to pipe laying, misalignment of pipelines and variations in gradients increases the chances of blockages and affects hydraulic performance. The most likely cause of this is poor construction and backfilling which is likely to cause problems related to subsidence and misalignment allowing movement of the pipe.

It is therefore important to consider the importance of bedding and backfilling as these influence the resultant in situ strength and the structural performance of the buried sewer pipe.

The bedding and backfill may be classified according to the bedding factor which indicates the relative increase in strength of the in-situ pipe compared with the strength measured by the bearing moment test.

3.4.1 Excavation and preparation of the trench

The nature of the ground, the depth of the trench, and the need to avoid damage to existing underground structures will determine the method of excavation and the need for structural support to the sides of the trench during construction.

Clay soils, cemented soils, and gravel soils are generally stable under dry conditions. Silty and sandy soils are less stable and, although not a common problem in Pakistan, care should be taken during construction in all types of ground under wet conditions.

Uniformity of support for a sewer is essential and the trench bottom should be carefully trimmed to the required depth and gradient to provide the proper formation level. The bedding at the joints should be over-excavated to enable the joint to be formed and to prevent the pipe resting on the socket.

The recommended trench widths for tertiary sewers and house connections are shown in Table 3-5.

Table 3-5 Recommended trench widths

Pipe diameter	Depth to pipe invert			
	2 ft.	4 ft.	5 ft.	6 ft.
	in.	in.	in.	in.
4 in	16	20	26	28
6 in	18	24	28	30
9 in	20	28	30	32

If the trench has been over-excavated and does not provide continuous support, low areas should be filled in with suitable compacting material. A soft or uneven formation should be removed to an economical depth and the resulting cavity refilled with a material that can provide uniform support.

Rocks, boulders or other hard soil should be removed from the bed level and replaced with backfill material. A layer of aggregate may occasionally be required, but this is generally not necessary for tertiary sewers in fine grained soils and relatively dry conditions.

3.4.2 Pipe laying

After the trench has been dug (with trench support if necessary) and the bedding prepared, the pipes should be laid alongside the trench prior to laying. Pipe laying should start at the downstream end and if spigot and socket type, the pipes should be laid with the socket facing upstream. Care should be taken not to damage the ends of the pipes during laying and not to allow bedding material to enter the joint and become trapped in the jointing.

One of the causes of problems in sewers is the failure to remove debris that has entered the sewer during construction. Sediment can be washed into the sewer trench during storms until manholes and chambers have been constructed and particular attention should be paid to ensuring that the sewer is free from construction debris. Where solids have entered the sewer during construction, it may be necessary to remove the material by dragging a ball of material attached to a rope through the pipe.

Manholes and chambers should be completed as soon as possible after the sewer pipe has been laid to ensure that there is no opportunity for storm water to enter the excavation.

3.4.3 Methods for laying pipes

Pipes should be laid true to line and level within tolerances as specified in Table 3.1. Checks will be necessary to ensure that pipes are laid according to the specified design gradients. This is especially important where the gradient is flat and the tolerances become more critical to variations.

The conventional approach to laying sewers to level is to use a `traveller' between `profiles' set at a given height above the required sewer invert at intervals along the sewer line. The correct level of the sewer at any point can then be determined by lining up a "traveller",

The traveller consists of a flat wooden board nailed to a second length of wood to form a `T' with the stem of the `T' the length necessary to fix the bottom level of the trench, the top level of any bedding or the invert level of the pipe as appropriate.

In Pakistan, an alternative method is commonly used by government engineers. Measurements are made from a string line, which is stretched between profiles set across the sewer line at intervals. The profiles are laid across the sewer and placed on bricks on either side rather than firmly fixed to a secure stake.

Both of these methods are reliant on levels which are fixed using a surveyors level. There is considerable room for error as community members and contractors rarely have either access to a surveyor's level or the ability to use it.

Small contractors and `mistries' often use alternative methods (water level and carpenter's level), to determine levels for laying pipes. The water level involves use of a transparent plastic tube (5mm internal diameter) which is open at both ends and filled with water). Sufficient space is left in the tube for a column of air.

Since the water in the tube is subject to atmospheric pressure, the water level at both ends of the tube is the same and may be used to measure the fall in the sewer. Care should be taken to ensure that air bubbles are removed from the hose.

3.4.4 Backfilling

In existing practice, many sewer trenches are filled all at once with little or no effort made to compact the back-filled material. The inevitable result is settlement, which takes place over time and may reach 6 in. or more in total, leading to failure of any surfacing that is provided in the weeks or months after the sewer has been laid.

Existing soil may be used for backfilling provided that care has been taken to ensure that the bed is well prepared prior to the laying of the pipe and the backfilling is well-compacted in layers. In these situations, the bedding factor is 1.1.

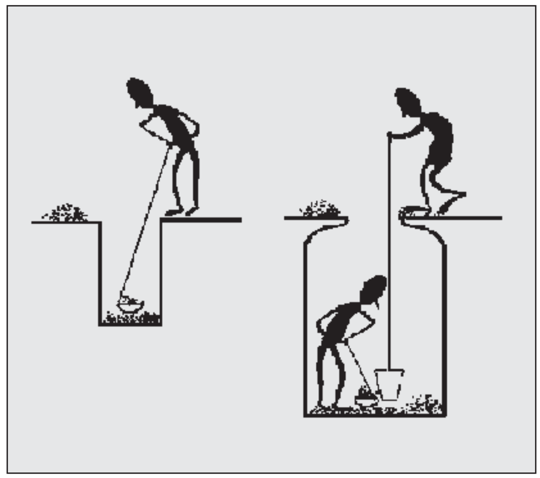
Backfill material must be well compacted to provide support to the pipes and prevent movement. Sewer trenches should be backfilled in 6 in. layers and backfill should be free of all hard materials, e.g. bricks, vegetation and rubbish. Dry backfill soil may be moistened to help it achieve maximum density during compaction.

Each layer should be compacted before the next layer is introduced. This practice reduces the risk of settlement of the fill material after backfilling has been completed. The need for proper backfilling and compaction should be emphasised in the training of supervisors for community managed sewer construction work.

3.5 Manhole and access chambers

Access chambers enable inspection and cleaning of chamber from the street surface using suitable cleaning equipment without the need for man to enter the sewer. Manholes are deeper and, as the name implies, enable a man to enter the chamber for inspection and cleaning of the sewers (see Figure 3-8 and Table 3-6).

Figure 3-8 Access chamber and manhole cleaning operations



The majority of chambers in tertiary sewerage systems will be an access chamber, but where the invert of the sewer pipe is greater than 3 ft. deep, then a manhole will be required. Based upon the standard WASA manhole, FAUP developed an alternative brick manhole that can be used for sewers where the inverts are between 3 ft. and 5 ft..

Table 3-6 Recommended sizes for access chambers and manholes

	Depth to invert	Internal Diameter
Access chamber	< 3 ft.	22 in.
FAUP Brick Manhole	3 ft. - 5 ft.	36 in.
WASA Brick Manhole	> 5 ft.	Varies according to depth

Benching

Benching is required to direct flow through the chamber, without any change in velocity in order to reduce the settlement of materials. The depth of benching should be finished off at the crown of the sewer.

For manholes, access and maintenance is also made easier by having a hard surface to stand on which is above the water level in the sewer. The benching should be of 1:3:6 concrete and may be surfaced with a well-towelled layer of 1:2 cement: sand mortar.

Construction of access chambers

The cost of materials and labour for concrete is approximately half that of brick. Concrete access chambers are therefore considerably cheaper than brick chambers and there is also no need for rendering.

FAUP access chambers have been constructed of 1:2:4 concrete using metal shuttering. In the absence of vibrating equipment, the concrete should be carefully worked into place by means of spades or steel rods with flattened ends. Figure 3-9 shows the concrete access chamber construction prior to backfilling.

The design details showing the dimensions and specifications for access chambers and manholes are shown in Figure 3-10 and 3-11. The specifications of the covers for access chambers and the surround details are described in greater detail in Section 3.5.1.

Figure 3-9 Concrete access chamber construction prior to backfilling

Figure 3-10 Tertiary sewerage system access chamber

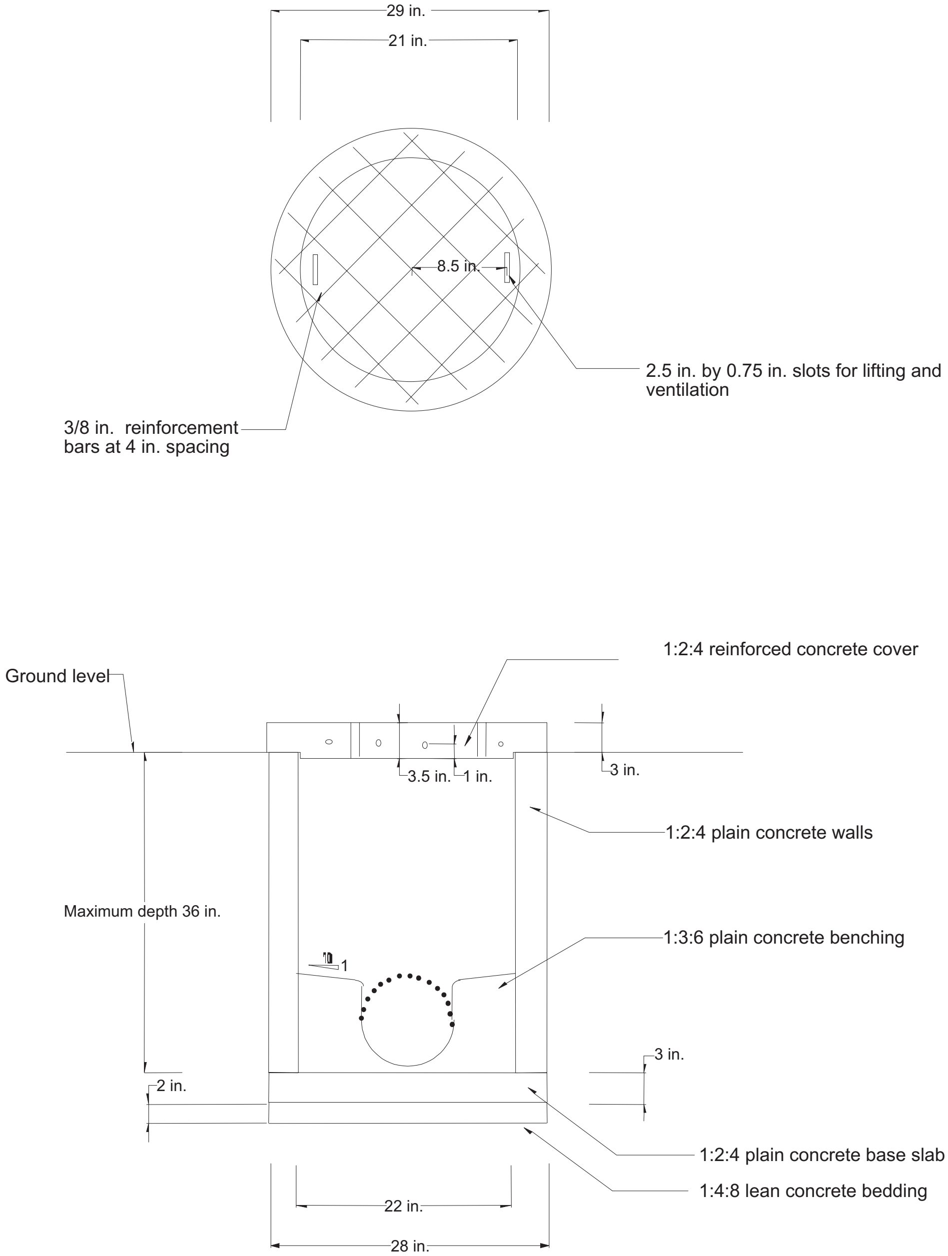
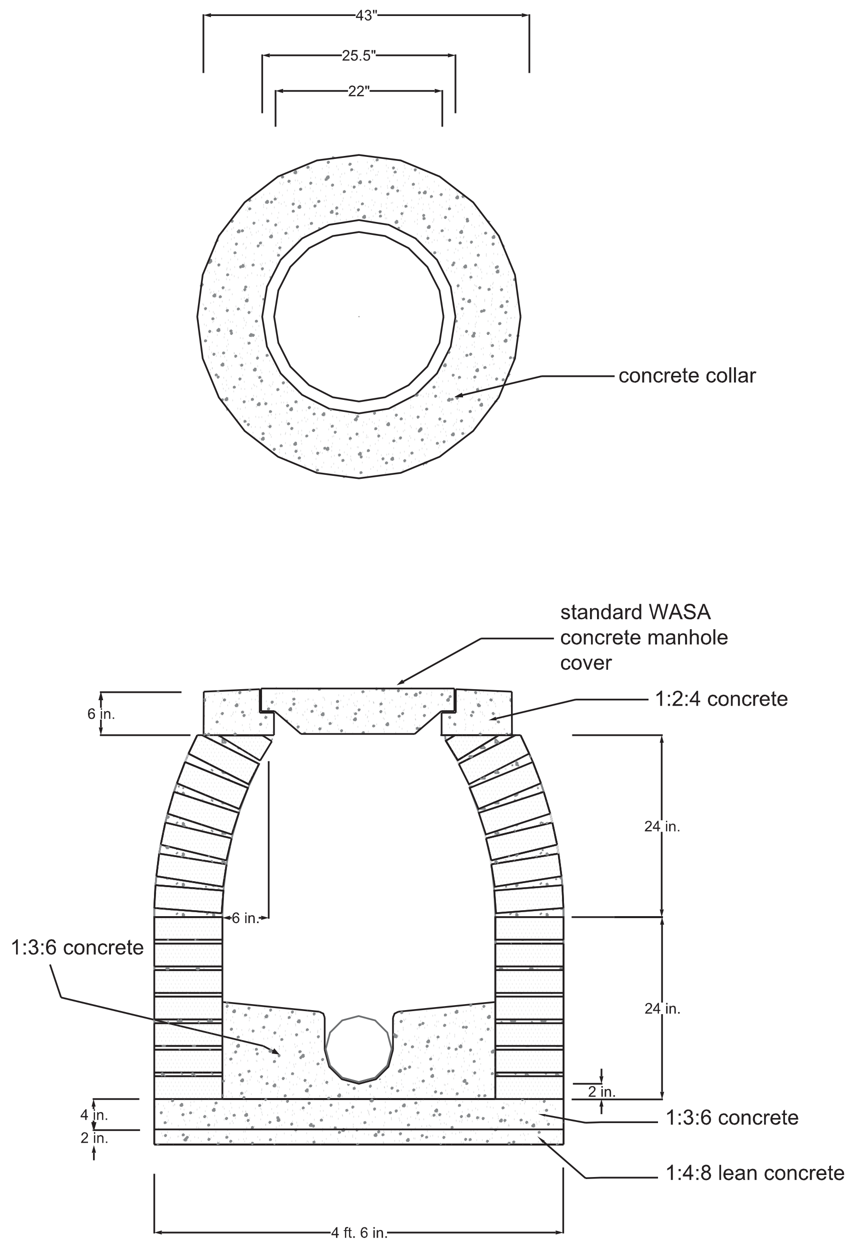


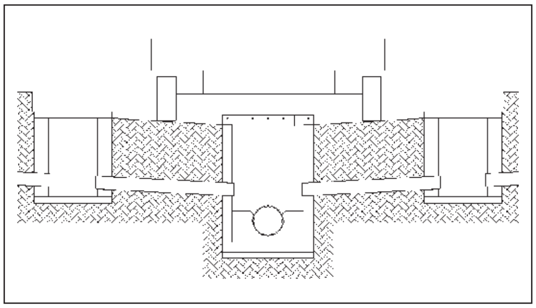
Figure 3-11 Tertiary sewerage system manhole



3.5.1 Access chamber covers

Access chamber covers need to be strong enough to withstand the traffic loading. In residential streets and especially in narrow lanes, it is not necessary to use the standard WASA manhole cover which is designed to withstand heavy loads in busy streets.

Figure 3-12 Road cross section showing wheel loads in relation to access chamber



Loads in the lanes of the katchi abadis are significantly less than on the main streets. It is recommended to reduce the thickness of the cover as described above and by locating the access chambers along centreline of lanes, away from wheel tracks (Figure 3-12).

The advantages of using a smaller cover are related to cost and the smaller cover is lighter making the chamber more accessible for inspection and cleaning. The reduced weight of steel used for reinforcement makes them less attractive to those who are tempted to steal the covers to recover and sell the metal for scrap.

The covers that were tested were of 31/2 in. thickness at the centre fabricated using 1:2:3 concrete mix and reinforcement of 3/8 in. diameter reinforcement bars at 4 in. spacing in both directions with a minimum cover of 1 in. to the base of the cover. These are located to ensure maximum resistance to bending moments from imposed loads.

A number of options of removing manhole covers from access chambers and manholes were considered. Based upon the fieldwork observations, the most appropriate arrangement for lifting involves holes in the cover. The proposed modifications to the manhole cover design include four 21/2 in. by 3/a in. slots in the cover to allow for lifting and ventilation.

The cover of the access chamber should include a surround in order to improve the replacement of the cover and to protect the cover from lateral loads. Two alternative designs are proposed; one of which uses a circular brick arrangement (see Figure 3-13) and the other includes the provision of a simple concrete surround cast to street level (see Figure 3-14).

3.6 Connections to the tertiary sewerage system

Pipes for house connections may vary according to the requirements of the householder, but the minimum recommended pipe diameter of house connections should be 4 in.. A small diameter pipe is cheaper and less likely to be damaged by traffic loads than a large one. Connections should be trapped to avoid the risk of gas, odours and providing access for vermin to and from the sewers.

Households connections to a tertiary sewer may be 4 in. diameter PVC pipes or 6 in. concrete pipes. The quality of PVC pipes varies considerably and the cost increases according to quality. Low quality PVC pipes tend to have thin walls and tend to become brittle and break easily. The PVC should be sufficient to withstand the corrosion from septic sewage. Therefore, a suitable quality PVC for sewage is recommended and comparable to concrete made to BS or ASTM specifications.

According to the Lahore Development Authority design specifications, it has been proven that drop pipes, for sewer connections entering manholes at elevations of more than 2 ft above the manhole invert, quickly become clogged and cannot be properly maintained, and so should be avoided. The recommendation concludes that the slope of the connection pipe should be selected to avoid any drop of 2 ft. or more.

Figure 3-13 Access chamber surround - concrete

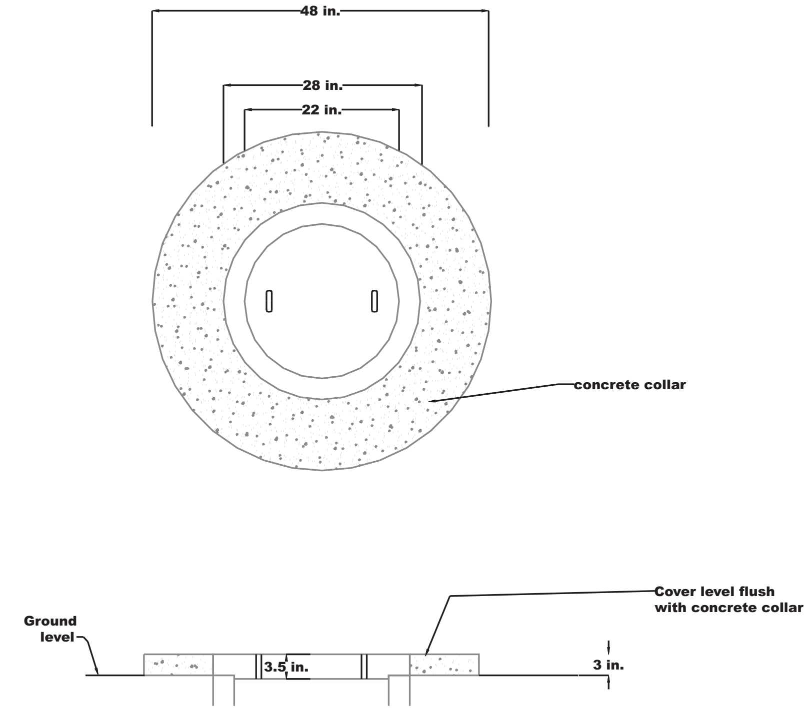
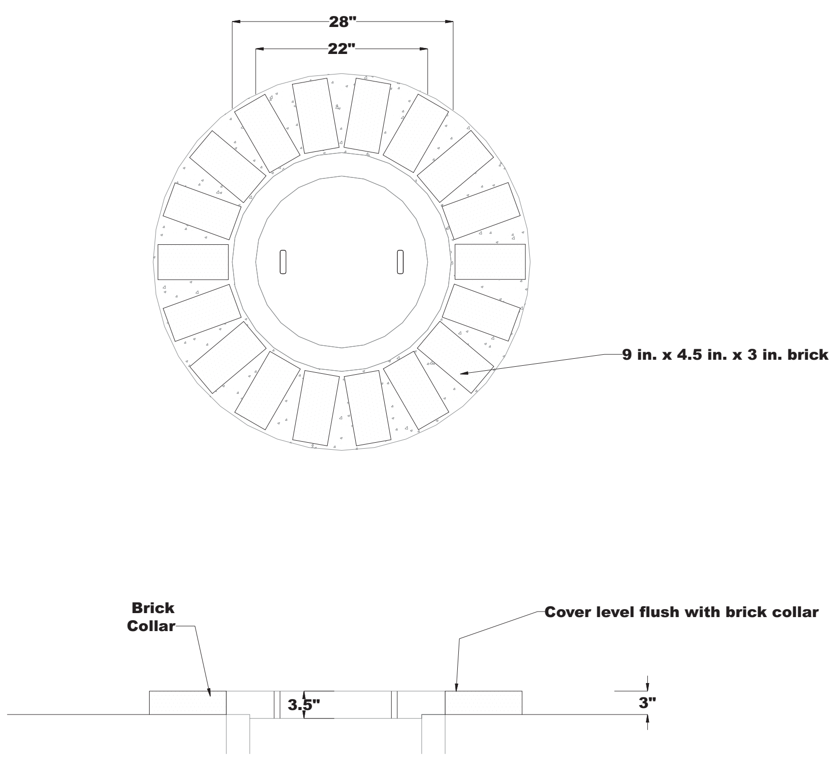


Figure 3-14 Access chamber surround detail - brick



3.7 Interceptor tanks

Interceptor tanks are recommended for the design of tertiary sewerage systems, especially where gradients of sewers are limited. Primarily, these tanks reduce the amount of solids entering the sewer; thus improving flow conditions and minimising maintenance requirements in the sewerage system.

Table 3 7 summarises the main advantages and disadvantages of the installation of haudi chambers as an integral component of the sewerage system.

Table 3-7 Advantages and disadvantages of haudi interceptor tanks

	Advantages	Disadvantages
Household level	None	Extra cost Sludge removal from haudi
Communal (tertiary) level	Reduced sedimentation and frequency of sewer blockage	Siting of haudis may cause obstruction in the land roadway
Secondary and primary level	Reduced sedimentation Reduced pumping damage Reduced pollutant load	Sludge requires a location for treatment and disposal.

The main design features of the haudi include a Tsection of pipe attached to the effluent pipe which blocks when the sludge solids accumulate to the bottom level of the T-pipe. At this point, the water level rises and the wastewater will back up the pipe, which may act as an indicator to the householder that the chamber requires cleaning.

As it is the householders responsibility, the design and quality of construction tends to be highly dependent upon the amount of money that the householder is prepared to spend and the mason that is employed to undertake the work.

If these tanks are designed so that the outflow pipe is above the base of the chamber, the storage volume attenuates flow and the tank acts as a sedimentation tank. Where the outflow pipe is located at the base, the tank offers little benefits to reducing the solids load.

Although the installation of haudis was not an integral part of the FAUP design, recommended design and construction of household connections and chambers (P-traps and gully traps) formed part of FAUP and these were promoted through awareness raising workshops.

Two alternative designs for the haudi are shown on the following pages

1) Figure 3-15 shows the design that should be adopted where faecal solids are not entrained in the tanks and this should be used where there is no reliable system for cleaning the tanks and disposing of the waste appropriately.

2) Figure 3-16 shows an alternative design that may be used where it can be assured that faecal waste collected in the tanks will be disposed of in a hygienic manner.

Figure 3-15 Brick haudi

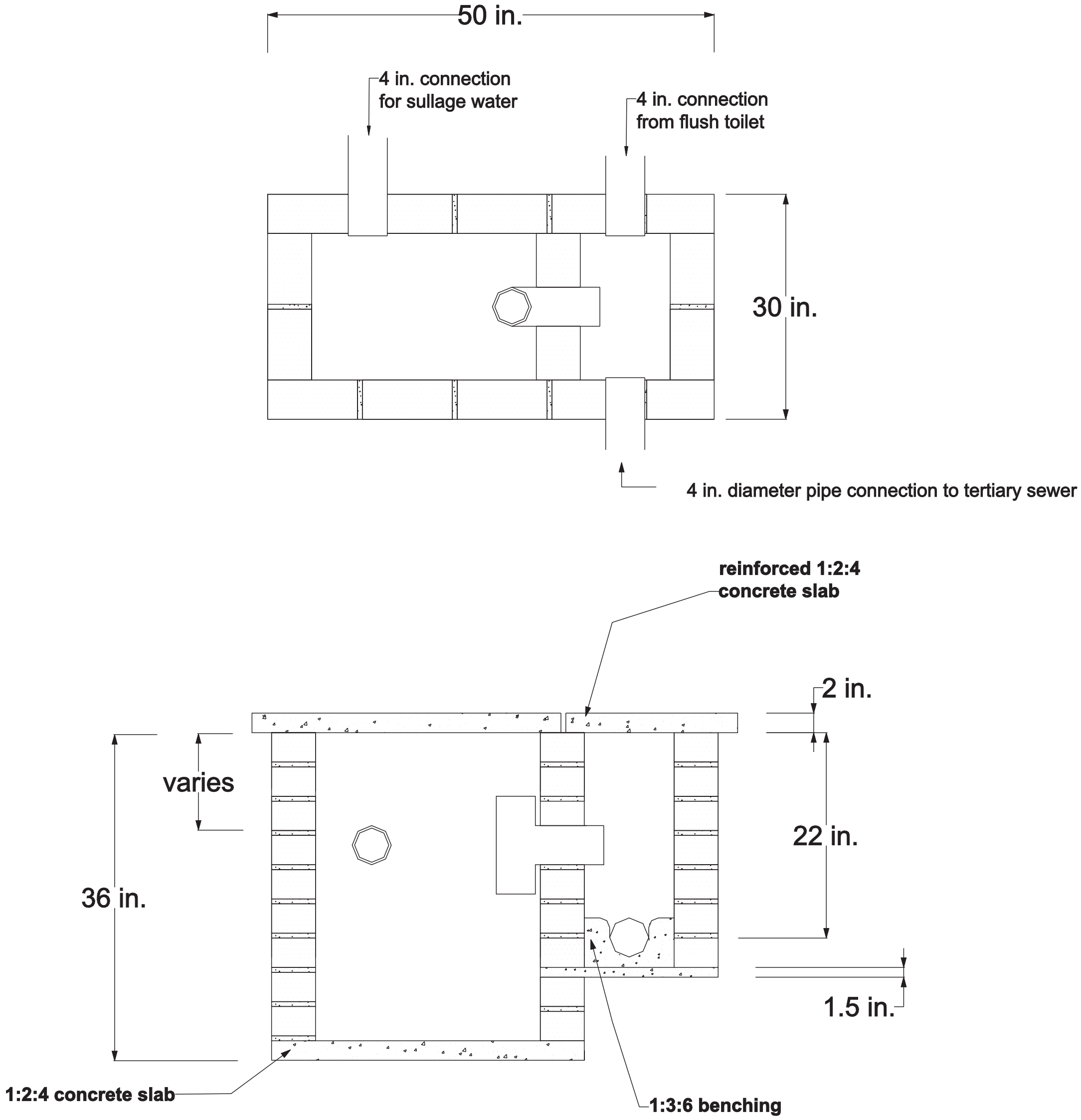
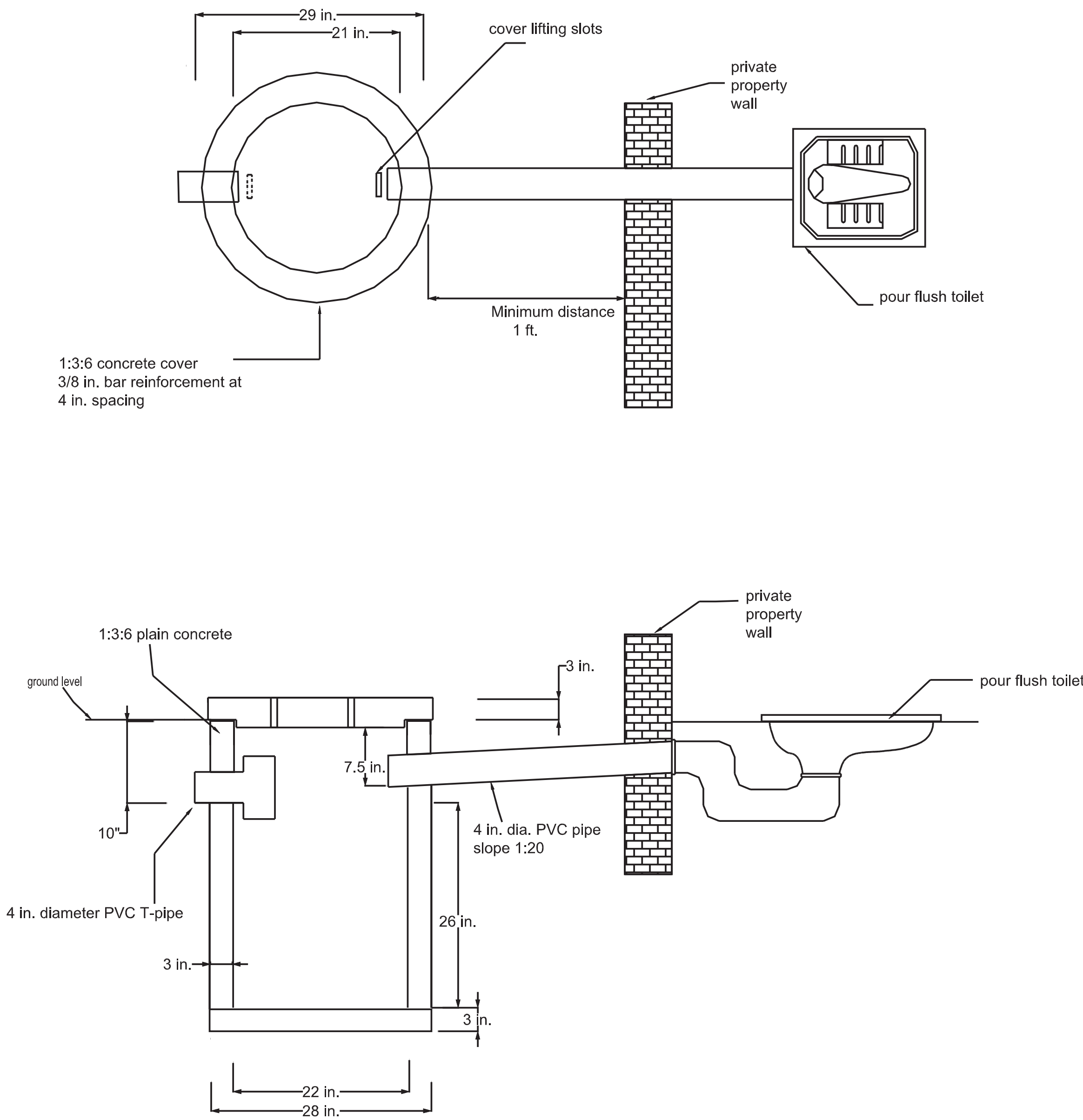


Figure 3-16 Concrete hanudi



4.0 OPERATION AND MAINTENANCE

Based upon fieldwork to investigate operational performance of sewers, evaluate maintenance requirements and alternative forms of sewer cleaning equipment, this chapter describes the requirements for sewer cleaning and the maintenance of household connections and interceptor tanks.

4.1 Structural condition of sewer pipes

Structural condition of pipelines and joints is difficult to assess accurately where systems are silted or partially obstructed with solid waste. The sewage is often backed up due to blockages or low pumping in the secondary and primary sewerage system.

Observations show little evidence of sulphate attack in tertiary level sewers and corrosion of pipelines in the FAUP tertiary sewers is not perceived to be a widespread problem. In other tertiary sewers where the flows are maintained, aerobic conditions prevail. However, due to inadequate ventilation, problems of corrosion were observed in deeper secondary sewers, notably on the inside of manhole covers.

Corrosion of concrete by sulphuric acid is common in pipelines where the wastewater is anaerobic. Hydrogen sulphide gas is produced from sulphates in the wastewater and the gas dissolves in water to form a corrosive acidic solution. The acid reacts with the chemical composition of concrete causing pipelines to decay and eventually collapse. The crown of the sewer is particularly prone to corrosion.

Corrosion is accelerated in tropical climates where ambient temperatures are high. The rate of decay of concrete tends to be greatest where the cement content and density of the concrete is low, allowing the acid to be readily absorbed into the concrete, rather than attacking its surface.

Hydrogen sulphide production is known to be greatest in heavily silted sewers, and where sewage flow is sluggish or stagnant. However, sewers which flow full under surcharged conditions are not generally affected because the gas stays in solution.

4.2 Operational problems

Theoretically, sewerage systems are designed to be hydraulically "self-cleansing". In principle, this means that the flow of wastewater is sufficient to transport suspended solids and other particulates along the length of the sewer to the point of discharge.

In Pakistan, this is rarely achieved in practice and sewers invariably suffer from siltation and blockage problems. In Faisalabad, the problems are compounded by the flat topography and by the hydraulic surcharge in the sewerage systems caused by the operation of downstream pumping equipment in the primary sewerage system with a high water level in the sump in order to reduce power costs and hence save money.

Intermittent water supply means that peak flows of wastewater are pronounced during the hours of the day when the water supply is on. Many of the intensive water consuming domestic activities associated with cleaning are concentrated during these times and the resultant wastewater flow rates are large in comparison with the average daily discharge.

Figure 4-1 illustrates the problems of sewer blockage causing overflow of sewerage into the street.

Figure 4-1 Overflow of sewage from blocked sewer

In Faisalabad, the most common operational and maintenance problems in sewers relate to the heavy siltation in the sewer lines and frequent blockages caused by larger solid waste.

Broken or missing manhole covers enable the ingress of sediment and domestic refuse into the sewerage system.

Normal silt and sediment loads in household wastewater should not cause any significant problems to sewers provided that they have been laid to design gradients and there is sufficient flow to transport the waste along the sewer. However, due to the lack of road surfacing, paving and widespread construction activities, the sediment load is very high and sewers invariably suffer from reduced flow due to sedimentation.

Although officially banned by recent legislation, some communities, especially in peri-urban areas (e.g. Chak 7), still keep buffalo and the disposal of buffalo faeces, either into open drains which flow into sewers or directly into the sewerage system itself, causes hydraulic problems due to the lack of sufficient flows of water to cleanse the conduits of this waste.

Blockages are caused by larger solid waste material consisting of a wide range of domestic refuse material to larger stones and masonry. Observations suggest that many sewer blockages are caused by materials deposited into sewers at chambers and manholes (including pieces of broken cover). Poor solid waste management exacerbates this problem considerably.

Staff from the WASA Operation and Maintenance department report that plastic bags and rags are one of the most frequent causes of sewer blockages. However, there is a wide range of solid waste material that finds its way into the sewers and consolidated silt is a persistent problem.

4.3 Sewer cleaning operations

WASA is responsible for cleaning and maintenance of secondary sewer lines, whereas FMC is responsible for cleaning of open sewers. Neither of these organisations is able to effectively perform its duties due to a lack of staff and cleaning equipment. As a result, blockages in the secondary system cause a backup of sewage in the tertiary sewerage system.

The problems facing WASA operations and maintenance department are exacerbated by the improper use of sewers by the public as well as government-employed municipal workers. Solid waste is sometimes dumped into the drainage system as a convenient location for dispose than the local solid waste transfer station.

This is particularly problematic for open channel drains but is also a problem for sewers where access chamber and manhole covers are missing, removed or broken.

Operation and maintenance of tertiary sewerage systems is officially the responsibility of WASA, but due to the need for frequent cleaning, a lack of staff, resources and equipment, there is a considerable backlog. As a result, communities often resort to paying for private sewer cleaning when the sewer becomes blocked. On average, this costs the household Rs. 30, although this may range from between Rs.5 to a maximum of Rs. 100.

In general, sedimentation and blockage were observed to be the cause of reduced hydraulic flow capacity of sewerage systems and contribute to the poor operational performance. The results from the fieldwork also indicated that once problems arise, they often become persistent. There is little or no proactive maintenance work and work to remove blockages is essentially an emergency measure (Box 4-1).

Box 4-1 Sewer cleaning in Noor Pura

The majority of maintenance activities are related to sewer cleaning. However, these tend to be responsive to specific complaints or identified problems and there is insuffucient time or resources to carry out a more extensive programme of problem identification and rectification.

Community representatives in Noor Pura reported few complaints during the first year after construction, but subsequently they claimed that they were paying to have the sewer cleaned on a monthly basis. This suggests that cleaning operations have been ineffective.

4.4 Sewer cleaning equipment

The successful removal of blockages is dependent upon nature of the blockage and a range of equipment is required for sewer cleaning operations.

Sewers may be cleaned mechanically using high pressure jetting equipment to dislodge consolidated material followed by removal by suction by vacuum tankers. These are used predominantly for the larger secondary and trunk sewers. The pressure jetting is 2000 PSI and thus cannot be used to clean poorly constructed sewers or sewerage systems constructed using pipes that fail to reach the WASA standards relating to structural integrity.

The majority of tertiary sewers are located in inaccessible neighbourhood lanes, which are not easily reached by the vehicles carrying the mechanical cleaning equipment. Alternative equipment has been tried by WASA, such mechanically powered steel rodding equipment, but this was found not to be powerful enough and is disused.

As a result, lane sewers are more suited for rodding by hand. The existing bamboo and metal rodding equipment (See Figures 4-2 and 4-3) used by WASA Operations and Maintenance staff is generally adequate for removing blockages sufficiently to allow for flow of sewage, but is not effective at removing silt from sewers. Figure 4-4 shows the rudimentary equipment employed to removed silt from manholes.

Figure 4-2 Cleaning sewers using wooden rods

The maximum length of the split bamboo is 25 ft. These are often wired together to increase their length, but this increases their stiffness, limiting access. Steel bars may be longer, but flexibility needed to enter the pipe limits the depth to which these may be used effectively. As a result, in tertiary sewerage systems such as those implemented through FAUP chamber spacing should not exceed about 50 ft.

Figure 4 3 Cleaning sewers using flexible

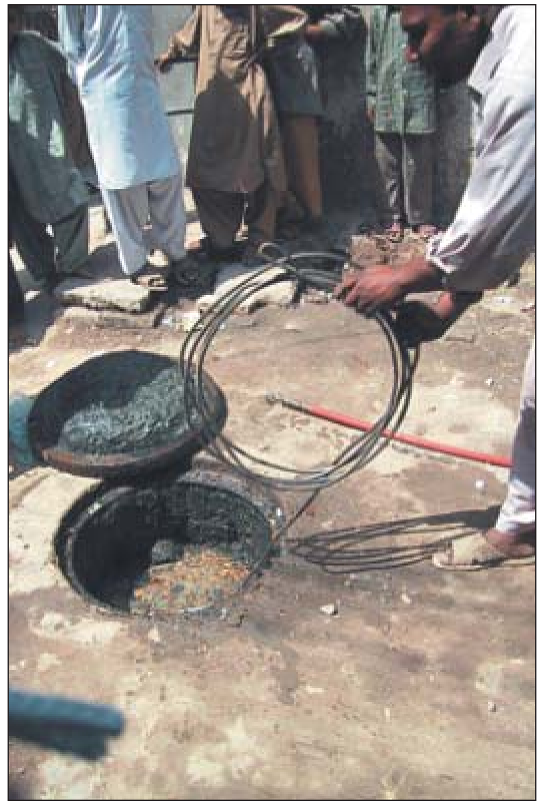


Figure 4-4 Equipment for removing silt

The study involved an evaluation of the merits of adopting equipment designed and manufactured specifically for cleaning smalldiameter sewers. The equipment manufactured in the United Kingdom consisted of 50 ft of NuflexTm rods and handle with various cleaning attachments (Figure 4-5) including an auger borer a plunger and a silt breaker.

The handle is used in conjunction with the silt breaker and the auger borer to provide the torque to the rod which is transmitted along the length of the rods and is translated into a turning action of the attachment fitted onto the other end of the rod. The lockfast joints are designed to ensure that the rods can be turned in either direction and the screw threads will not become loose.

Figure 4-5 Accessories and attachments for sewer rodding equipment

The order of usage of the three tools should be firstly, the silt breaker, secondly, the auger borer, and lastly the plunger. However, depending on the nature of the sediment or blockage, it was not always necessary to use all three.

Figure 4-6 shows the typical composition of silt which was observed to be a fine organic silt. This becomes a compacted with larger solids which can be very difficult to clean. The screw action associated with the auger borer and silt breaker was found to be considerably effective at disturbing sediment beds & deposited solids.

Figure 4-6 Compacted silt removed using the auger borer

Based upon practical experience, the recommended maximum depth for use of this equipment is 6ft, which is sufficient for tertiary sewerage systems. The sewer rodding equipment was used effectively to clean sewers up to 9 in. diameter and was used to clean up 50 ft. of pipe.

Field tests indicated that a minimum of 20-30 minutes per sewer length between manholes is required to effectively clean one section of sewer pipeline between two manholes. It was observed that it was harder to clean the first section of pipes downstream from the access chamber. This may be attributable to the fact that manholes are the entry point for solids into the sewerage systems and blockages are more likely to occur in these locations.

Figure 4-7 Inserting the rodding into the access chamber

In practice, the main limitations were observed to be related to the flexibility of rod and the time required to connect sections of rod together. Nevertheless, although the rodding equipment was found to have its limitations, it proved to be effective for cleaning small- diameter sewers.

The rodding equipment is particularly suitable for small sewers, sewers which have low strength, sewers in narrow streets, and for cleaning sewers which are blocked with compacted sediment. (See figure 4-7)

Other advantages of the rods related to the fact that the equipment requires no mechanical machinery, they can be transported easily and require minimal training. Although WASA staff reported that equipment might prove to be a useful additional tool for sewer cleaning, they expressed a number of reservations and suggested some modifications that may be required. These related to the length of the rod sections, the total length of the rodding equipment, and the need for reduced flexibility in the rods.

4.5 Impact of haudis

Although, recommended design and construction of household connections and chambers (P-traps and gulley traps) formed part of FAUP, the installation of haudis was not an integral part of the FAUP design. In Addition, a sewerage system in Hasan Pura, which also used Haudis installed on each house connection and promoted by NGO ASB was surveyed.

The level of siltation and solids in the sewer was observed to be considerably less than those in other areas where haudis were not properly designed or constructed. The benefits of installation of haudis improve the performance of the sewerage system as a whole, reducing operational and maintenance requirements and frequency of sewer cleaning operations.

However, it was apparent that haudis had not been cleaned as the level of solids was observed to be very high.

The majority of haudis in other areas were not generally well designed and have the inflow and outflow pipes in the bottom of the tank (with no T-pipe) and thus are simply acting as connection boxes rather than sedimentation chambers.

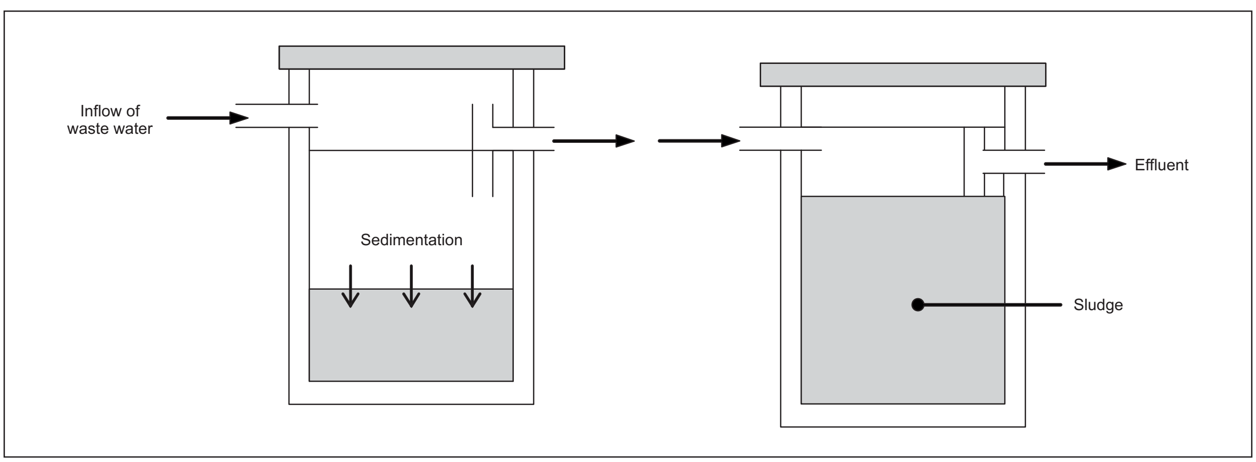
The incorporation of haudi interceptor tanks is an integral part of the proposed design specifications for tertiary sewers in order to reduce the solids load on sewers and enable the sewers to be laid at shallower gradients.

Since January 2001, FAUP has also started using haudis in all of its Chack-7jb pilot project area.

The disadvantages with the installation of haudis are associated with the extra financial cost, the need for desludging every 2-3 years, and the hygienic disposal of sludge which becomes the responsibility of the householder.

Figure 4-8 illustrates the hydraulic and physical processes inside the chamber of a haudi which influence the cleaning. The reduction in solids and resultant build-up of solids in the tank is a function of the concentration of the wastewater and the available retention volume. As the sludge accumulates in the tank, the retention time reduces and the resultant efficiency of solids removal is reduced. Eventually, the tank becomes full and the outlet pipe may become blocked.

Figure 4-8 Hydraulic and physical processes in the haudi chamber



If the outflow T-pipe is correctly installed, then the haudi will continue to allow wastewater to flow into the sewer, even when it is full of sludge. This provides a useful indicator means to evaluate when the haudi requires cleaning. However, T-pipes are not always fitted and sometimes were fitted incorrectly either due to lack of knowledge or negligence of the mason haudis need to be cleaned and provision needs to be made for the tanks to be inspected and cleaned on an annual basis, or more frequently if solids build-up is large.

Cleaning of interceptor tanks is critical to the sustainable operation, as once they become full they become ineffective in removing solids. For maintenance, the main parameters to consider are discharge and concentration of wastewater, the time between cleaning, and the volume of the tank

The available options include manual methods using buckets and simple containers, methods using manually operated pumps and various methods using mechanically operated pumps.

Simple manual desludging methods are found in many countries. The equipment required includes buckets, some form of sludge container mounted on a handcart and the hand-tools required to break up consolidated sludge. The pit contents may also require flushing and dilution with water prior to emptying.

4.6 Disposal of solids

Most sanitation systems which retain faecal solids and sediment on site require that the retained solids are removed from time to time. Removal systems should not present a risk to the health of the workers carrying out the service and disposal arrangements should be such as to ensure that the removed faecal material does not present a threat to either health or the environment. The solids collected in an interceptor are likely to be hazardous to human health, especially if they are connected to a toilet.

The silt and sludge removed from access chambers, manhole, sewers, and haudis is frequently septic and harbours many pathogens There is a lack of health and safety standards relating to sewer cleaning practices (Figure 4.9) and there is need for protective equipment (gas masks, goggles, gloves) for the sewermen.

Figure 4-9 Lack of health and safety procedures

The existing practice of emptying pit contents from access chambers, manholes and sewers onto the street prior to removal by FMC road sweepers is not satisfactory especially where solids contain excreta due to the health risks (Figure 4-10). The silt and sludge removed from access chambers, manhole, sewers, and haudis is frequently septic and harbours many pathogens

This is particularly important in residential areas where excreta is relatively fresh and pathogen content is high and children play in streets with no shoes. An improved system for handling sludge and solid wastes removed from sewers is required.

Figure 4-10 Sewer cleanings emptied on the street

4.7 Wastewater reuse for irrigation

Deliberate blockages and structural modifications were observed in Chak-7 and Noor Pura to the sewerage system to divert flows of sewage from the sewerage system to the surrounding fields for irrigation. This practice has been adopted since the introduction of piped water supply in peri-urban areas. Unlike the groundwater supplies, the tap water is of low salinity and therefore more suitable for crop irrigation.

The use of wastewater for irrigation is beneficial where alternative sources of irrigation water are limited. The wastewater irrigates crops and the nutrients in the wastewater also provide a valuable source of fertiliser to promote the vegetable growth. However, there are significant public health risks with these practices especially where the crops grown are for human consumption.

Demand for wastewater for agricultural reuse is highest during the dry seasons which can result in widespread water shortage and reduced flow in irrigation channels. The reuse of wastewater is recognised by farmers to be beneficial for both irrigation and fertiliser. Where the water supply is unmetered, farmers may encourage excessive consumption of water for wastewater reuse (Figure 4-11).

In some locations where the drainage system is not working efficiently, residents are reported to pay local farmers to accept the wastewater onto their land. This is as a result of the failure of the tertiary sewerage system to drain the wastewater to the secondary system.

The International Water Management Institute (IWMI) recently carried out a survey in Harronabad in Punjab Province to evaluate the health risks associated with reuse of untreated wastewater for irrigation. This study concluded that wastewater contains far more faecal coliform bacteria and helminth eggs than advised by WHO guidelines, which poses a high health risk particularly to farmers who subsequently suffer from increased incidence of gastro-intestinal diarrhoeal diseases and hookworm infections. Crop consumers are also at risk where the irrigated crop is consumed directly. However, risks are reduced where crops are used for animal feed.

Figure 4-11 Wastewater reuse for irrigation in Noor Pura

In comparison with the populations in two other peri-urban villages which use other sources of water for irrigation, the health status of the farming community in Harronabad was significantly affected by the prevalence of diarrhoeal diseases. The farm workers and children with barefeet were especially prone to hookwook infections.

IWMI recommends appropriate wastewater treatment to the concentration of pathogens in the wastewater prior to reuse. Where treatment is not economically viable, a range of protective measures for farmers, their families, and crop consumers are proposed. These include promoting increase community awareness of the risks associated with wastewater reuse, shoes and gloves for farm workers, and treatment of the afflicted families with anti-helminthic drugs.
In general, there is greater potential for WASA to sell treated wastewater to farmers for reuse and tariffs could be developed accordingly.

An important issue relates to the design of the sewerage system itself. Community representatives from Chak-7jb who participated in a focus group discussion requested that the system should be designed to enable farmers to utilise the wastewater when required without resorting to blockage of the sewer. They were aware of the benefits of wastewater reuse, but were also concerned about the effect that the existing practice would have on their sewerage system.

5.0 LESSONS LEARNT AND KEY RECOMMENDATIONS

5.1 Design of tertiary sewerage systems

5.1.1 Minimum diameter of tertiary sewer pipes

The minimum diameter pipe was investigated in relation to the capital costs of tertiary sewerage infrastructure and the implications on the operational performance of the systems. In theory, a 6 in. diameter pipe may be appropriate for tertiary sewers and in some locations, these pipes have been used to construct some community sewers.

However, in practice, the sustained operation of these system is dependent on regular maintenance of the system. As settlement of solids and blockages are inevitable, there is a reluctance to accept a reduced pipe diameter by government agencies as well as amongst community members.

Further investigations are necessary to investigate whether the causes of blockages are directly attributable to the smaller diameter pipe or whether there are other factors. Until there is evidence to suggest that a 6 in. diameter pipe is practically feasible, the minimum diameter for pipe for tertiary sewerage systems should remain at the existing PHED standard of 9 in.

5.1.2 Gradient of sewers

The sewers should be laid to maximise the available fall in the ground levels at the surface. The most economical design is often that in which the gradient of the sewer is of the same order as the general surface of the ground. However, where ground levels are flat, sewers should be laid at gradients to produce velocities which are sufficient to transport solid particles in the wastewater under normal flow conditions.

The sewer should be designed so that peak velocities erode any sediment that has deposited in the invert of the pipe. The greater the diameter of the sewer, the flatter is the self-cleansing gradient at any given proportional depth of flow in the sewer. The velocity of flow in a circular pipe of a given diameter and gradient is the same when running either flow or half-full. At intermediate stages between half-full and full, the theoretical velocity is slightly greater, but the velocity drop progressively as the flow falls below the half-full stage.

Practical experience demonstrates that the scouring effect of sewage carrying road grit and other abrasive materials in suspension is not a serious problem. Since the construction of a sewer at a steeper gradient can be appreciably cheaper than building backdrop manholes, an upper limit of velocity to avoid scour is not of significance in the design. In particular, in Faisalabad and other cities where ground levels are flat, problems of scour are not appreciable as sewers are unlikely to be laid at steep gradients.

The design self-cleansing velocity is usually taken as 2.5 ft. sec 1, but where haudi interceptor tanks are used in the design, the design velocity may be reduced to 1.5 ft. sec 1. In practice, this effectively means that the design gradients for 9 in. diameter tertiary sewers are as follows:

Gradients - without haudi	
Recommended	1:150
Minimum	1:200

Gradients - with haudi	
Recommended	1:300
Minimum	1:400

5.1.3 Distance between access chambers and manholes

As access chambers and manholes are one of the most expensive components of the tertiary sewerage system, the system should be designed so that the number of chambers is sufficient to minimise the length of house connections. However, in order for an economical design, the distance between access chambers should be between 50 ft and 70ft.

5.1.4 Depth of sewers

FAUP sewers have been constructed at depths of 3 ft. cover from ground level to invert. These have not resulted in any operational problems and a minimum cover depth of 3 ft. is recommended for tertiary sewers in lanes less than 15 ft. wide where traffic loads are lower than in the wider busier streets.

In exceptional circumstances, where the sewer cannot be laid to cover depths of 3 ft (for instance due to existing water supply or gas pipelines), the pipe should be protected from surface loads by a reinforced concrete slab.

Sewers should be laid as such depths as will accommodate not only existing properties, but also future properties likely to be erected within the area which the sewer is designed to serve. The plinth level of the house rather than the existing ground level should be taken into consideration in the design of the house connections as this will enable the gradient of the connection to be maximised without affecting the depth of the tertiary sewer.

5.1.5 Beddiniz and backfill

Existing soil may be used for bedding providing due care is taken to ensure that the bed is flat and laid with due care.

The backfill becomes a load bearing structure, particularly in trenches under roads, and it therefore needs the same care and attention in its execution as any other structure. Backfilling should commence as soon as possible after the completion of the bedding, but allowing time for mortar joints or concrete to harden sufficiently to avoid damage.

The soil from the excavated trench can be used for backfill material, but care should be taken to remove larger stones (greater than 1 in. in diameter), lumps of clay, tree roots, rubbish and organic matter. Care should be taken during backfilling to reduce unnecessary overloading of pipes. The depth of fill should be kept uniform over the length of the pipe and the fill should not be tipped or pushed into the trench.

Backfill should be placed in 6 in. layers and carefully compacted without excessive surface pressure. This backfill should be added until the depth of backfill reaches 1 ft. above the crown of the pipe. The remaining backfill should also be added in 6 in. layers with hand ramming to ensure greater compaction nearer the surface.

The method of backfilling aorund manholes should generally be the same as for trenches and should be carried out as part of the same operation. Care should be taken to raise the fill equally around the manole shaft in order to avoid unbalanced lateral laoding.

5.1.6 Access chambers and manhole covers

Due to lack of suitable alternative to the standard WASA brick manhole for shallow sewers, FAUP constructed tertiary sewers have used two types of chamber. For sewers less than 3 feet deep (to invert), a concrete access chamber having an internal diameter of 22 in. is constructed in-situ concrete. This is similar to that used by the NGO OPP The concrete should be placed as soon as possible after mixing and thoroughly compacted by rodding, tamping, or vibration so as to form a void-free mass around the reinforcement and into the corners of the formwork or excavation.

The design of these chambers offer considerable cost advantages over brick manholes. Some modifications to the design are proposed for future construction. These include benching in the base of the chamber and a new manhole cover. The key features of the manhole cover include an increased depth in the centre of the cover to improve structural bearing capacity and to improve the positioning of the cover in the chamber. The cover may also include slots for in order to improve lifting and replacement, which also act as ventilation of the sewer and allow ponded surface water to drain slowly into the sewer. The manhole cover also includes a surround detail of brick or concrete to protect the cover.

Manhole covers should be pre-cast in approved manufacturing yards which satisfy the requirements of the relevant government agency (WASA or PHED). Covers should be fabricated using concrete and reinforcement that satisfies the relevant specifications. The minimum cover reinforcement should be 1 in. from the base. Covers should be compacted using a vibrating table and cured for a minimum of 4 days.

Where the sewer is laid to a depth where the cover depth is greater than 3 ft. but less than 5 ft., a brick manhole is recommended. FAUP developed a brick manhole based upon the existing WASA manhole, but with a reduced diameter of 36 in.

5.1.7 House connections

Where gradients are flat, construction of haudi interceptor tanks are required for household connections in order to remove solids. The installation of T-pipes in the haudi provides an effective means of improving the performance of chambers to reduce the ingress of sediment and solid waste into the sewerage system. The T-pipe also provides an indication to the household when the haudi needs cleaning, when the level inside the tank rises to the top level of the T-pipe.

5.2 Construction Specifications

5.2.1 Reinforcement

All reinforcement used in construction should be new and should satisfy the relevant Pakistani standards.

5.2.2 Cement

Ordinary Portland cement which satisfies British Standard BS 12 should be used for fabrication of all concrete pipes, precast concrete units (such as manhole covers) and construction of sewer ancillary structures (access chambers). Concrete should be mixed using a mechanical mixer wherever possible until there is a uniform distribution of the materials and the mix is uniform in colour. The concrete should be transported from the mixer to the place of final deposit as rapidly as possible as practical by methods which prevent the segregation or loss of any of the ingredients.

5.2.3 Water

The water used for mixing concrete should be clear and free from solid particles. The water cement ratio should 0.65 for 1:3:6 concrete and 0.6 for 1:2:4 concrete.

5.2.4 Curing

Care should be taken to ensure that concrete is kept damp during curing and concrete should be cured for a minimum of 4 days. To check that the concrete is the required quality, samples should be taken at the point of placing and works cubes made, cured and tested according with the requirement of BS 1881 (Methods for testing concrete). The frequency of testing is a matter for the regulating agency (WASA or PHED) who should develop and agreed procedure for quality control.

5.2.5 Aggregatestes

The quality and grading of aggregate used to make concrete should be such as to produce a concrete of the specified quality which will readily get into position without segregation and without the use of excessive water.

The nominal maximum size of coarse aggregate should be as large as possible, within the limits specified in the appropriate standard. This is to ensure that the concrete can be placed without difficulty, by the means of compaction, so as to surround all reinforcement thoroughly and to fill the corners of the formwork.

5.2.6 Mortars

Uniform fine sand should be used for mortaring. Coarse sands may be suitable provided the coarser material is removed by screening through a wire mesh. For brickwork mortar, the cement:sand ratio should be 1:3, for jointing or pipework, between 1:2 - 1:3 and for rending of brickwork, inverts or benching, 1:2.

5.2.7 Bricks

Care should be taken to ensure that bricks used for construction of manholes are of sound quality and preferably should comply with BS3912. Bricks used for construction of haudi interceptor tanks should be sound and visibly free from defects.

5.3 Manufacture of concrete pipes

Based upon the pipe tests, considerable variations in the quality of concrete pipes were observed. WASA pipes produced in approved yards are theoretically manufactured to specifications ratified by Pakistani Government Authorities. However, in practice, based upon the pipe testing results, many 9 in. diameter pipes notably those produced by non-WASA approved manufacturers, do not comply with the official government standards derived from BS 5911 Pt 100.

These pipes were found to have low structural integrity due to low cement content, use of second hand steel for reinforcement, and poor quality aggregates. Generally, poor attention was paid towards the accurate measurement of quantities of concrete constituents, and the water:cement ratio. Generally, the pipes were not cured properly.

Where poor materials are used and there is no attention to the amount of water, the concrete is weak, leading to low durability and failure at low loads. This is attributable to inadequate quantities of cement, soft and/or weak aggregate, poor bonding between the cement and the aggregate, due to dust and smooth surfaces.

The results from the research indicated that the manufacturing methods of concrete pipes adopted by many pipe casting yards produce pipes which do not meet the official government specifications. Pipes from small yards had very little strength and could easily be broken with a hammer. This was even true of some of the pipes chosen at random from officially approved casting yards.

The tests and visits made to the factories showed that: none of the pipes tested conformed to the requirements of BS 5911, Pt 100. Concrete strength would have to increase significantly for them to do so. Major improvements in the quality of materials and methods used are also required in most factories.

The following deficiencies were noted in small informal casting yards in Faisalabad:

Use of poor quality aggregates (typically ¼ in. brown shale).

Poor control over quantities of cement:sand:aggregate ratios.

Lack of control of water:cement ratios which are normally much higher than the optimum.

Use of scrap steel for reinforcement and wide spacings of hoop steel, which result in longitudinal bars being forced outwards to the outer face of the pipe during spinning.

Pipes were often cured for only one day and cured in water of low-quality.

Although these deficiencies are particularly apparent in the smaller unregulated yards, there is considerable room for improvements in all yards, including those that are ratified by WASA to produce pipes that meet government standard and attain the relevant British and American standards.

The results indicated that a few improvements in the pipe manufacture procedures resulted in significant improvements in pipe strength. In particular there is a need to focus on ways of reducing the costs of the higher quality pipes without compromising on quality. Improved pipe strengths may be achieved at marginal increases in pipe cost if greater attention is paid to using better quality aggregate and measurement of concrete materials, and the water cement ratio.

The results from the testing showed that concrete pipes for non-WASA schemes could be made stronger with little implications on the overall cost. A 1:3:6 concrete mix is recommended and this may be achieved at no extra cost by using the cement that is currently used for lining the pipes. The increase in concrete strength would enable the quantity of reinforcement to be reduced.

5.4 Quality Control Procedures

Reductions in government approved standards for pipes quality are technically feasible for tertiary sewerage systems, but the lack of an adequate system to ensure that these standards are adopted means that reductions in standards should only be considered when the systems for enforcing these standards have been developed. At present, government agencies lack sufficient resources to effectively monitor and regulate pipe casting yards to enforce existing standards. Greater attention needs to be paid towards developing improved quality control systems.

Also, the cost of any improved pipes are significantly higher than the cheapest commercial pipes. Unless there can be substantial reductions in the cost of production, without affecting quality, it will be difficult to encourage communities to use better quality materials, even if their use can be justified from a technical point of view.

A critical point to emerge from the pipe testing programme was that there is a need to improve quality control procedures to ensure a reasonable pipe quality. Improvements in the structural strength and durability of concrete may be achieved by ensuring greater control of material quantities and quality, and also the methods used to make concrete sewer pipes.

Pipes which are sold commercially are widely claimed to be of `ASTM standard'. Manufacturers rarely make any reference to `BS standard' pipes. Although there are generally no records of any tests to verify these claims, on the basis of the observations and the pipe testing, it was concluded that the majority of pipes in the market are unlikely to comply with this standard.

Most attempts to assure customers of the quality of pipes refer to the amount of reinforcement and the concrete mix used. In the smaller pipe production yards, there is little attempt to provide any quality assurance, as the cost is the main factor of concern to the buyers of these pipes.

Supervision of the manufacturing process was observed to result in improved pipe quality. Therefore, further technical assistance to pipe manufacturers may result in significant improvements in pipe quality with no additional cost implications.

The importance of improved evaluation and monitoring of casting yards in order to improve quality control procedures, especially of the small-scale yards, cannot be overemphasised. It may be advisable to provide community representatives with some basic training in what to look for in a well managed casting yard.

The accepted standards of manufacturing and quality of building materials and products should apply to pipes, which should be promoted as structural items. This should include the production of simple literature in local languages which promotes good advice on good and bad features of pipes, pipe making and factories. The Schmidt Hammer may be used as a nondestructive test for routine monitoring to assess quality of concrete in the pipes.

Provided that the manufacturing processes are monitored to ensure quality of production, quality improvements may be achieved where components (e.g. manhole covers) are pre-cast off-site. Access chambers may also be constructed using pre-cast units of large diameter concrete circular cross-sections. Precast, manufactured goods require prescribed standards and tolerances by which the finished product or batch is judged and quality control procedures are vital within the overall manufacturing process.

It is unreasonable to expect that 100% of items produced will satisfy the specifications, but careful control of the manufacturing process will reduce the defect rate and inspection of the finished product will ensure that the number of defective items entering the marketplace is kept to a minimum.

5.5 Construction procedures and site supervision

The fieldwork highlighted certain deficiencies in construction related to the lack of control of standard construction procedures. Some of the pipelines that were surveyed were constructed using pipes that satisfied WASA official specifications, but no sewer collapses or severe structural deficiencies were observed or reported.

Although structural deficiencies in the pipelines were not observed to be a significant problem, it was not possible to gauge whether problems will arise at a later date due to poor quality workmanship. However, the gradients of pipelines were observed to be highly variable, and in some instances, were laid to negative gradients. This is attributable to poor workmanship and inaccurate methods for laying the sewer.

Greater attention should therefore be made to ensure that pipes are laid at design gradients and setting out procedures are important to ensure that sewers are laid to correct levels. During construction care should be taken to prevent ingress of construction debris and sediment into sewers and good backfilling is essential to ensure that sewers retain structural integrity

In order to ensure that sewers and access chambers are constructed according to design specifications, adequate care and attention needs to be made to ensure good quality workmanship. Good construction procedures and site supervision is essential if sewers are to be constructed according to design standards and construction specifications.

Construction work should be clearly indicated by simple contract documentation and construction good practice guidelines to provide guidance and instructions on recommended construction procedures. The standard design details, linked to schedules of costs and quantities, should be used to provide information required by site staff. Diagrams and photographs should be incorporated to illustrate important features of design and construction.

A government approved certified training course for small-scale contractors is advisable. Communities may request to see the contractor's training certificate prior to employment. If the contractor is subsequently responsible for poor construction, the community may submit a complaint to the government agency. Linked to this is the need for an organisation that is suitably equipped to carry out the training. This organisation should have the capacity to provide short, focused training courses and also to advise and provide technical assistance to communities on a longer-term basis.

5.6 Operation and maintenance

Larger solid material that enters the sewerage system will require cleaning for removal and the sewerage system should be designed to facilitate access from the surface (see access chamber and manhole design) and to enable the use of suitable sewer cleaning equipment.

The fieldwork evaluated the operational performance of sewerage systems and demonstrated the importance of effective maintenance for the sustainable operation of tertiary sewers.

The fieldwork demonstrated the effectiveness of sewer cleaning equipment and, in most situations, the equipment proved to be suitable for cleaning tertiary sewers. However, further testing of sewer cleaning equipment is required to evaluate effectiveness and durability.

The equipment may be manufactured locally using locally available materials, such as bamboo with brass connections, at a considerably reduced cost. Alternative materials should be costed in the market to evaluate the price of manufacturing the equipment in Faisalabad. The rods need to be balanced between strength, flexibility and durability.

There is a need for adoption of appropriate health and safety standards relating to sewer cleaning practices. In particular, sewermen need protective equipment. Where it is necessary for a man to enter a manhole for inspection or cleaning, it is necessary to supply goggles, gloves, and breathing equipment.

There is a lack of sanitary disposal of solid waste that is removed from access chambers, manholes and sewers. The existing practice of emptying pit contents onto the street prior to removal by FMC road sweepers is not satisfactory especially where solids contain excreta.

Tertiary sewer cleaning operations may be combined with local solid waste collection and disposal. Reductions in cost of cleaning operations may be achieved where a service is undertaken at the lane level as oppose to at the single household level.

Alternative arrangements for operation and maintenance may be considered in which WASA offers maintenance contracts to the private sector or, subject to negotiation, responsibility for operation and maintenance may be handed over to local CBOs or NGOs.

Control of sediment and solids is a complex institutional problem in terms of operation and management. However, provided solids interceptor tanks are constructed and cleaned on a regular basis, the problems associated with sewer siltation and blockage may be effectively mitigated.

Some relatively simple measures to improve solid waste management can be promoted which provide considerable benefits in terms of operational performance and the cost of maintenance and sewer cleaning.

Responsibilities for operations and maintenance need to be addressed to ensure sustainable operation of these systems within the framework of the various government line agencies responsible for drainage, wastewater and solid waste management.

Operation of tertiary sewers is dependent upon the operation of downstream pumps in the primary sewerage system. Insufficient pumping or operation of the pumps under surcharges conditions severely impedes the flow of sewage in the secondary sewerage network which has implications for the effective operation of tertiary sewers.

5.7 Scope for replication

Figure 5-1 summarises the strengths and weakness of the proposed design specifications documented in this report. The 'opportunities' and 'threats' refer to the scope for adoption and wider scale replication.

Traditionally, government services providers are not experienced in liasing with communities and communities are often sceptical of government initiatives. Experience from FAUP demonstrates the key role of the Community Infrastructure Unit in facilitating communications and acting as an intermediary between the government engineers and the community groups.

Adoption of appropriate specifications may require additional promotion to ensure that local stakeholders understood them and are implemented accordingly.

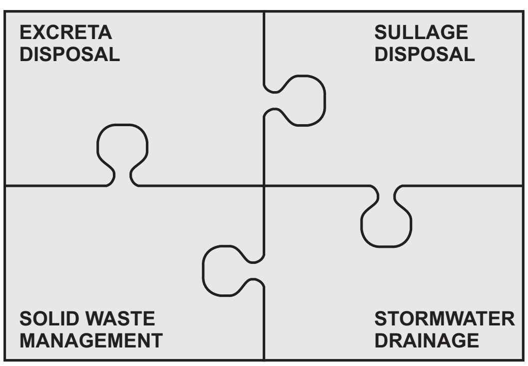
In cities like Faisalabad, due to the flat topography, it is critical that plans for improved sanitation at the local level are developed and implemented within context of the need for wastewater disposal.

Figure 5 1 Strengths, weaknesses, opportunities, and threats to replication of the FAUP low-cost sewerage model

Strengths	Weakness
Manhole covers are designed for easy of lifting and replacement and enable drainage of surface water. Benching promotes efficient flow through access chamber and low depth of sewer improves accessibility for cleaning. Concrete access chambers are more suited shallow sewers and are easier to construct than brick manholes. Surround detail protects access chamber and manhole cover. Haudis offer an effective means of reducing the solids load into the sewerage system	Strength of concrete pipes is dependent upon quality of raw materials and quality control procedures. Quality of construction is dependent on the training and skills of local contractors. Cleaning of sewers and chambers requires disposal of solid waste. Cost of haudis will increase the overall cost of tertiary sewerage systems. Haudi interceptor tanks require cleaning.
Opportunities	**Threats**
Promotes local enterprise in operation and maintenance. Community involvement in during construction promotes monitoring of quality of construction. Enables government to target investment on primary and secondary infrastructure	Sustainable operation of tertiary sewers is dependent upon operation of secondary and primary sewers. Many still find it hard to contribute. Lack of regulation of contractors may lead to poor quality construction.

An integrated approach towards sanitation is required in which excreta and sullage disposal, stormwater drainage & solid waste management are effectively managed within a comprehensive city-wide strategy (see Figure 5-2)

Figure 5-2 Integrated approach to sanitation



Lack of comprehensive planning of the sewerage network as a whole for existing communities and future developments may result in underdesign of the secondary sewerage system, cause problems at a later stage if tertiary sewerage systems are planned and implemented on a piecemeal basis.

Well-intentioned efforts and investments may be wasted if communities construct tertiary sewerage systems without due consideration of the need for sufficient capacity in the secondary and primary sewerage system to drain the wastewater. It is therefore important that tertiary level infrastructure is incorporated in a comprehensive and integrated city-wide planning system.

The other benefit for installing the primary and secondary infrastructure is that it was seen to act as an incentive for community mobilisation for participation and financial contribution. Experience from FAUP demonstrated the importance of ensuring that primary and secondary sewerage systems are constructed prior to the mobilisation of communities and the construction of tertiary sewers. In areas where the secondary sewers were not in place, it proved difficult to mobilise the community

As a result, the FAUP approach towards the implementation of tertiary sewerage has developed since the early days and now advocates a more strategic and comprehensive sewerage infrastructure programme. This forms part of the neighbourhood area approach to infrastructure upgrading as advocated and practised by FAUP.

The Pakistan policy guidelines ratified at the National Seminar on Urban Environmental Sanitation in 1998 also concluded that all investments in sanitation should be planned in a holistic manner taking a city-wide approach, yet leaving flexibility to initiate activities in small steps and discrete areas of the city. This also fits in with the international agenda advocated by the World Bank's Strategic Approach to the provision of sanitation infrastructure and services.

Access chamber

	Length		Volume		Concrete mix			
	Inches	Feet	Cubic ft.		Cement	Sand	Aggregate	
Cost per cubic foot				* 1.54	200	6	10	
					1	4	8	
Bedding (1:4:8)			0.713	1.10	0.08	0.34	0.68	
Depth	2	0.17						
Diameter	28	2.33						
Cost					17	2	7	
Base (1:2:4)			1.069	1.65	0.24	0.47	0.94	
Depth	3	0.25						
Diameter	28	2.33						
Cost					47	3	9	
Walls (1:2:4)			4.91	7.56	1.08	2.16	4.32	
Internal dia	22	1.83						
External dia	28	2.33						
Depth	36	3.00						
Cost					216	13	43	
Cover (1:2:4)			1.25	1.92	0.27	0.55	1.10	
Depth	3	0.25	1.15					
Diameter	29	2.42						
Depth	0.5	0.04	0.10					
Diameter	21	1.75						
Cost					55	3	11	69.1
Benching (1:3:6)			1.17	1.80	0.18	0.54	1.08	
Depth	9	0.75	1.98					
Diameter	22	1.83						
Length	22	1.83	0.81					
Diameter	9	0.75						
Cost					36	3	11	
					Cement	Sand	Aggregate	
Total volume					1.77	3.72	7.44	
Cost per cubic foot					200	6	10	
Total cost of cement					354	22	74	451
Reinforcement bars		ft	lbs/foot	lbs				
3 / 8" bars		23.33		0.376	8.8			
No.* Length					Rs. per pound =		12	104
2*28 =	112	9.33						
4 * 24 =	96	8.00						
4 * 18 =	72	6.00						
4" PVC pipe		12			Cost per foot =		15	180
					SUB-TOTAL Cost of materials=			734
Excavation and backfilling			9.00		Cost per foot =		2	18
Depth	36	3.00						
Diameter	36	3.00						
						rate	days	
Labour	Skilled		200-250	per 8 hour day			225	0
	Semi-skilled		150-200	per 8 hour day		175	0.5	87.5
	Unskilled		80-130	per 8 hour day		100	1	100
TOTAL								940

Houdi with reinforced cover

	Length		Volume		Concrete mix			
	Inches	Feet	Cubic ft.		Cement	Sand	Aggregate	
Cost per cubic foot				* 1.54	200	6	10	
Base (1:4:8)			1.07	1.65	0.13	0.51	1.01	
Depth	3	0.25						
Diameter	28	2.33						
Cost					25.3	3.0	10.1	
Walls (1:3:6)			4.91	7.56	0.76	2.27	4.54	
Internal dia	22	1.83						
External dia	28	2.33						
Depth	36	3.00						
Cost					151.2	13.6	45.4	
Cover (1:3:6)			1.33	2.04	0.20	0.61	1.23	
Depth	3	0.25	1.23					
Diameter	30	2.50						
Depth	0.5	0.04	0.10					
Diameter	21	1.75						
Cost					40.9	3.7	12.3	56.8
					Cement	Sand	Aggregate	
Total volume					1.09	3.39	6.78	
Cost per cubic foot					200	6	10	
Total cost of cement					217	20	68	305
					1	4	8	
Reinforcement bars		ft	lbs/foot	lbs				
3 / 8" bars		23.33	0.376	8.8				
No.* Length					Rs. per pound =		11.82	104
2 * 28 =	112	9.33						
4 * 24 =	96	8.00						
4 * 18 =	72	6.00						
4" PVC pipe		10			Cost per foot =		20	200
T-pipe							Unit cost =	25
Cost of materials								634
Excavation and backfilling			9.00		Cost per foot =		2	18
Depth	36	3.00						
Width	36	3.00						
						rate	days	
Labour	Skilled		200-250 per 8 hour day			225	0	0
	Semi-skilled		150-200 per 8 hour day			175	0.5	87.5
	Unskilled		80-130 per 8 hour day			100	1	100
TOTAL								840
	grade 1	grade 2	grade 3					
4"	14	20	26					
one length -13"								
Elbow	20							
T -pipe	25							

Brick Houdi

					Cost per brick			
No. of bricks		222			1.5	333		499.5
100 cu. Feet		1352 bricks with mortar						
(including 6-10 bricks wasteage)								
		1400 bricks with mortar			Cement	Sand	Aggregate	
					200	6	10	
			Concrete mix		1	3	6	
Cover			0.85	1.31	0.13	0.39	0.79	
Depth	2	0.17						
Length	23	1.92						
Width	32	2.67						
Cost					26.2	2.4	7.9	36.5
			Concrete mix		1	3	6	
Base			0.85	1.31	0.13	0.39	0.79	
Depth	2	0.17						
Length	23	1.92						
Diameter	32	2.67						
Cost					26.2	2.4	7.9	36.5
Wire mesh reinforcement			Area					
	23	1.92	5.1		Rs. per sq. ft =		4	45
	32	2.67						
4" PVC pipe		10			Cost per foot =		15	150
T-pipe							Unit cost =	40
Cost of materials								852

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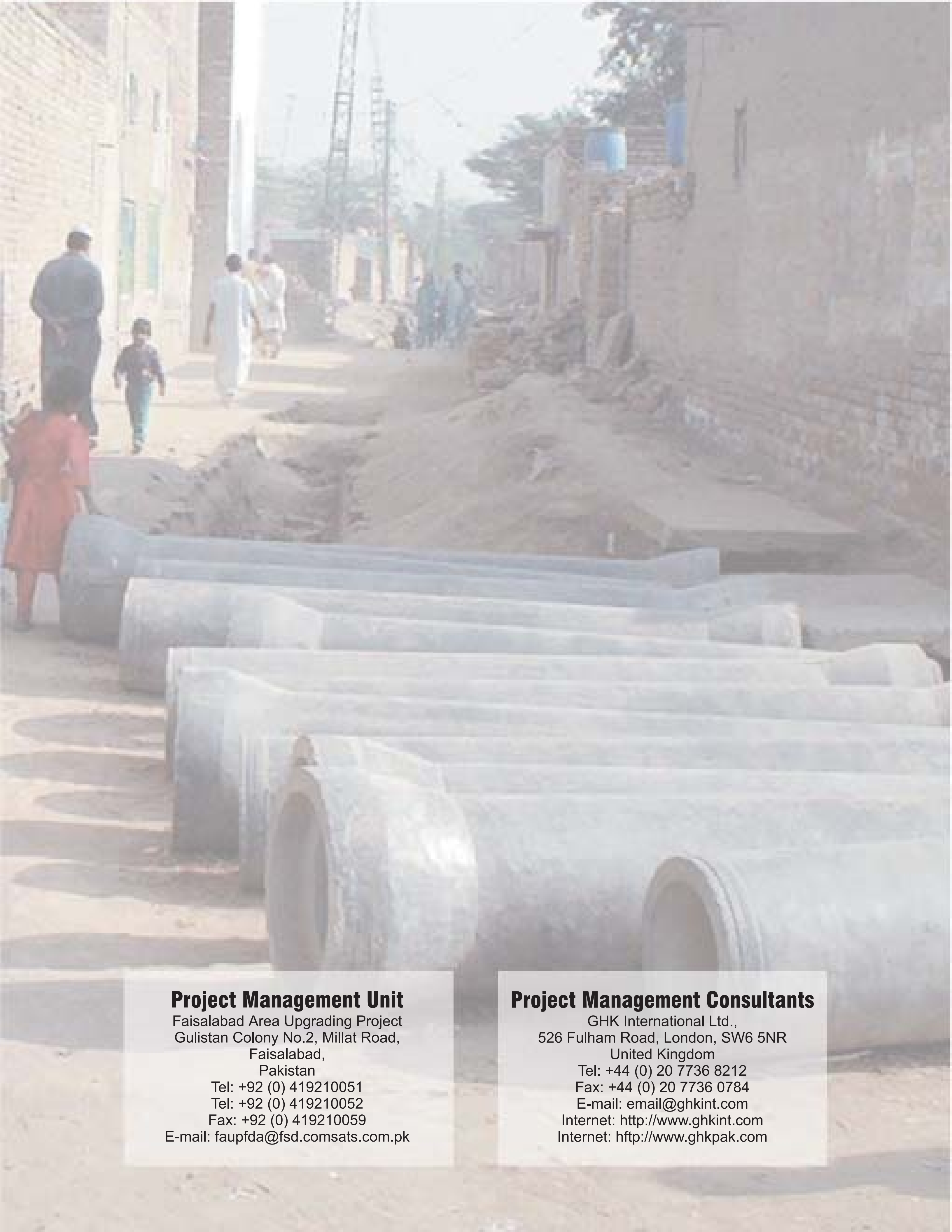
He is the project manager for the DFID funded Faisalabad Area Upgrading Project in Pakistan responsible for co-ordinating the activities of a diverse team of local and expatriate staff engaged in a multi-sectoral participatory approach to the upgrading of urban environmental infrastructure and social services. Mr. Alam joined the project in 1997.

Jonathan Parkinson - Civil & Environmental Engineer

Jonathan Parkinson is a civil and environmental engineer, specialising in the design of sanitation, drainage, and wastewater management systems. As part of Faisalabad Area Upgrading Project, he worked with WASA engineers to develop appropriate standards and specifications for the design and construction of tertiary sewers for use in low-income areas of Pakistan. He has also recently assisted in the production of a *'Guide to Strategic Planning for Urban Sanitation'* which includes material to assist in planning and decision-making for improved urban sanitation and wastewater management.

Back Cover: Sewerage pipes of appropriate specifications for use community based Tertiary level projects.



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