Cost-effective sewerage for communities

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COMMUNITIES IN PAKISTAN have been developing sewerage systems for many years, either on their own, or assisted by political leaders or NGOs such as Orangi Pilot Project (OPP). As part of its programme of poverty alleviation through community empowerment and partnership with government, Faisalabad Area Upgrading Project (FAUP) has been promoting community-based sewerage, using a model similar to OPP’s.

Because cost is a major constraint community-based sewerage projects rarely use materials and methods which conform to government standards. Line agencies are therefore reluctant to adopt them. They therefore receive no revenue, despite handling the sewage at some stage and incurring costs.

When asked if it would take over the community-based sewers promoted by FAUP the Water and Sanitation Agency (WASA), Faisalabad, expressed concern about construction standards. However, rather than leave the matter there, it also asked FAUP to investigate the subject, and recommend an appropriate and economic design for community-based sewerage that it could accept. It could then promote more cost-effective sewerage services itself, and communities would know that WASA could take over ownership and operation and maintenance, on payment of the appropriate charges.

GHK International is undertaking the investigation on behalf of FAUP, assisted by a local consultant. It is supported by the Department for International Development (DFID), UK, the main donor for FAUP. This paper describes an investigation of the pipes used in WASA and community systems, and some appropriate alternatives; and some of the conclusions and recommendations made. The work is being carried out in partnership with WASA staff, including the site testing. As Imperial measurements are used in Pakistan this paper uses their nearest metric equivalent.

**Existing systems and specifications**

Most tertiary level sewers, both government and private, comprise 225mm diameter reinforced concrete pipes, and brick manholes. The wall thickness of the pipes is usually 25mm. They are laid directly on the excavated ground, or granular material. Trenches are normally backfilled with selected excavated material. Manhole covers are reinforced concrete.

Government systems use spigot and socket pipes. They should conform to the current British Standard (BS 5911, Pt 100 (1988)). The minimum cover is 0.9m. The BS specifies minimum concrete parameters (approx. 1:1.5:3), and performance criteria, e.g. crushing load 25kN/m. Reinforcement is only used if required by the designer. In UK 225mm dia. pipes are unreinforced. Their wall thickness is 37mm.

The private and NGO systems generally use plain ended pipes. There are no performance criteria. Reinforcement varies and should be considered as nominal.

For further details of the pipes see Table 1.

**Pipes and covers for testing**

As well as testing the pipes currently in use, including some made to FAUP specification, some alternatives were also made and tested at a local factory. This was to compare a number of options. The alternatives chosen are detailed in Table 1. Eleven others were considered. They were not made or tested because of time and cost.

Making pipes with concrete less than 1:4:8 mix was not considered because of the low strength of these mixes, and possible problems handling the pipes when fresh, during transport to site (see below) and laying. Various reinforcement arrangements were considered, to improve crushing strength, and minimise the effects of poor compacting of backfill. Unreinforced pipes were not considered, also because of handling concerns, and the cost of increasing wall thickness to provide greater strength. Cost was already known to be a major constraint.

The main aim of testing manhole covers was to see if their weight could be reduced without reducing their strength, to make lifting and sewer cleaning easier. Covers with ribbed soffits were considered, but structural analysis indicated no overall savings over plane ones, and more complicated casting. Therefore only plane soffit covers were made and tested.

**Manufacturing**

**Existing production practices**

Visits to large factories, where WASA type pipes are made, and some small factories, where the other pipes are made, showed the following:

- concrete strengths probably lower than claimed by the manufacturers, due to:
  - only rough measuring of materials, using irregular size containers of unknown volume,
  - excessive use of water,
  - use of less cement than claimed,
  - loss of cement during spinning (contained in excess water),
**Table 1: Pipe test results**

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Spec'n (factory)</th>
<th>Reinforcement details</th>
<th>Concrete compressive strength, porosity</th>
<th>3 edge test - load (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Long bars (hoops/spiral)</td>
<td>Circular bars (hoops/spiral)</td>
<td>mix proportions</td>
</tr>
<tr>
<td>1.1</td>
<td>FAUP</td>
<td>8 x 4.8mm</td>
<td>7 x 2.4mm</td>
<td>1:4:8</td>
</tr>
<tr>
<td>1.2</td>
<td></td>
<td>6 x 4.8mm</td>
<td>13 x 2.4mm</td>
<td>1:4:8</td>
</tr>
<tr>
<td>1.3</td>
<td></td>
<td>9 x 2.4mm</td>
<td>24 x 2.4mm</td>
<td>1:3:6</td>
</tr>
<tr>
<td>1.4</td>
<td></td>
<td>9 x 2.4mm</td>
<td>24 x 2.4mm</td>
<td>1:3:6</td>
</tr>
<tr>
<td>1.5</td>
<td></td>
<td>24.4 mm spiral, @ 150mm c/c</td>
<td>1:3:6</td>
<td>25.4</td>
</tr>
<tr>
<td>1.6</td>
<td></td>
<td>Total weight, long &amp; spiral bars: 6.3 kg / 2.4m pipe</td>
<td>1:11:3</td>
<td>25.2</td>
</tr>
<tr>
<td>1.7</td>
<td>WASA (large)</td>
<td>4 x 4.8mm</td>
<td>5 x 7 x 2mm</td>
<td>1:2:4</td>
</tr>
<tr>
<td>1.8</td>
<td>comm/c'1 (small)</td>
<td>typical</td>
<td>typical</td>
<td>1:7:15</td>
</tr>
</tbody>
</table>

**Table 2: Manhole cover test results**

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Diameter (mm)</th>
<th>Thickness (mm)</th>
<th>Reinforcement (each way)</th>
<th>Concrete mix proportions, compressive strength, porosity</th>
<th>Ring bearing test, crack location &amp; load</th>
<th>Factory price, each (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mix</td>
<td>strength (N/mm²)</td>
<td>porosity (%)</td>
</tr>
<tr>
<td>2.1</td>
<td>555</td>
<td>65</td>
<td>5 x 12mm, 110mm c/c</td>
<td>1:2:4</td>
<td>25.4</td>
<td>6.6</td>
</tr>
<tr>
<td>2.2</td>
<td>555</td>
<td>110</td>
<td>5 x 12mm, 110mm c/c</td>
<td>1:2:4</td>
<td>29.1</td>
<td>4.6</td>
</tr>
<tr>
<td>2.3</td>
<td>635</td>
<td>85</td>
<td>5 x 12mm, 125mm c/c</td>
<td>1:2:4</td>
<td>25.0</td>
<td>6.6</td>
</tr>
<tr>
<td>2.4</td>
<td>635</td>
<td>110</td>
<td>5 x 12mm, 125mm c/c</td>
<td>1:2:4</td>
<td>25.2</td>
<td>6.6</td>
</tr>
</tbody>
</table>

**Notes:**
1. 25.4mm = 1", 1 kg = 2.2 lbs, 1 kN = 220.3 lbs, 1 kN/m² = 67.8 lbs/ft², 1 N/mm² = 1.42 x10¹⁰ psi, Rs40 = $1 (US)
2. Main gauge calibrated, but operating at very bottom of range: a secondary, non-calibrated, gauge with lower full scale deflection was obtained and used in conjunction with it, giving more consistent results.
3. A mixing of concrete observed for pipes 1.1-1.6, obtained by sample analysis for pipes 1.7 & 1.8, samples have neat cement lining, therefore mix proportions shown are probably over-estimates of actual mix.
4. Compressive strength obtained using Schmidt hammer, providing direct strength readings in N/mm².

- Aggregate usually brown shale (6mm down), which is soft, dusty and smooth, (only two factories seen using granite),
- Inadequate curing of the finished products (small factories only),
- Need for careful handling and transport to site, to avoid breakage (small factories only),
- Use of recycled wire and steel in small factory pipes,
- Up to 3kg of neat cement used to provide smooth finish to inside of pipe (average thickness 3mm),
- Unlike pipes brown shale is not accepted in other building products and in-situ concrete work.

**Making of the test items**
The factory pipes tested were selected at random to ensure that they were representative of normal production. The other pipes and the manhole covers were made under supervision, to ensure their quality. This would provide a better basis for making comparisons, rather than having data from pipes of unknown quality. Subsequently appropriate factors could be used, to allow for lower quality working, etc. Three samples of each pipe/cover were tested, to obtain more representative results.

The materials for the made pipes were all measured using containers of known volume. The water:cement ratio was controlled too, to provide a dry but workable mix, and minimise cement loss during spinning and the porosity of the finished pipe. The aggregate was mixed in the proportions 2/3 granite, 12mm down, and 1/3 shale, 6mm down, to provide a dense, well graded concrete. The neat cement lining was added, so that the pipe makers should feel that they had made real pipes! It comprises up to 35 percent of the cement used for a pipe of 1.4-8 concrete, and 20 percent for one of 1.2-4.

One immediate result of the investigation is that the factory where the pipes were made has now started to control its water:cement ratio. Less cement is lost, and stronger pipes are made, without increasing costs.

**Tests and results**
The tests undertaken were a Schmidt hammer test to determine the compressive strength of the concrete, a three-edge bearing test to determine the pipe crushing strength, and a ring bearing test for the covers. Bending moment resistance, and other data were not considered relevant to
Table 3: Material and pipe costs

<table>
<thead>
<tr>
<th>materials and pipe prices (Rs/m)</th>
<th>small factory as existing</th>
<th>1:3:6 concrete</th>
<th>FAUP type 1 kg lining</th>
<th>reduced steel</th>
<th>WASA standard as existing</th>
<th>1:1½:3 concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>materials</td>
<td>27.0</td>
<td>36.6</td>
<td>56.9</td>
<td>56.1</td>
<td>35.6</td>
<td>70.8</td>
</tr>
<tr>
<td>small factory</td>
<td>68.9</td>
<td>78.7</td>
<td>98.4</td>
<td>104.9</td>
<td>86.4</td>
<td>131.1</td>
</tr>
<tr>
<td>large factor</td>
<td>-</td>
<td>-</td>
<td>114.8</td>
<td></td>
<td>-</td>
<td>163.9</td>
</tr>
</tbody>
</table>

Notes: 1 also uses improved materials, i.e. granite aggregate and sharp sand 2 4 x 3mm dia longitudinal bars and 4 x 3mm dia, or 7 x 2mm dia hoops figures in italics are estimated costs

this stage of the investigation. In-situ tests of one set of pipes was planned for later. These tests would provide data to relate performance in trenches to crushing strength, according to cover, and vehicle loads in streets and lanes.

It was found that pipes made to FAUP recommendations were about twice the strength of the WASA standard pipes. They were also about four times stronger than the small factory pipes. It was also found that the pipes made under controlled conditions using 1:3:6 and 1:2:4 concrete were, respectively, about 25 per cent and 35 per cent stronger than the FAUP pipes. However, none of the pipes achieved the 25 kN/m minimum crushing strength required by BS 5911.

Increasing the amount of reinforcement only resulted in a small increase in strength. Only one set of pipes collapsed under load. They were from a small factory, and suspected of being much newer than advised. Another set, from another factory, were slightly stronger, and did not collapse.

None of the concrete complied with BS 5911. Analysis of the factory pipes showed concrete mixes between 1:4:18 and 1:8:13, and poorly graded (6mm down) brown shale aggregate. This is different from building materials, where brown shale is not accepted. Concrete is usually well cured too, and the amount of cement used and the water:cement ratio are watched carefully.

Concrete porosity was only slightly higher in several of the factory pipes, indicating that their low strength is due low strength concrete and not porosity. It is expected that most of the free water is removed during spinning, along with some of the cement too, increasing density but reducing concrete strength, which is probably already low.

More detailed results may be found in Table 1. The in-situ tests are being conducted on pipes of type 1.4 laid at different depths. Results are not yet available.

The tests on the manhole covers showed that it is possible to reduce thickness only by reducing diameter or load capacity. More detailed results may be found in Table 2.

Vehicle loads
A study has identified the maximum loads expected. They are largely governed by the width of a street, which limits the size of the vehicles that can use it. In narrow streets (4m) the heaviest is a horse cart loaded with bricks. In wider streets it is a single axle trailer, also loaded with bricks. Drivers and communities know that they risk the vehicles falling into sewers if they are too heavily loaded, and do not enter unless the load is reduced.

These data will be used to determine safe loads for the pipes, in conjunction with the in-situ test results.

Costs
Investigations of costs have shown that
- at small factories labour, overheads and profit are about 100 per cent of material costs, and 150 per cent at large ones,
- reinforcement is 10 -25 per cent of material costs for small factor pipes, and at least 50 per cent for the other pipes,
- the cement used to make concrete is 20-30 per cent of the material cost,
- using granite aggregate instead of shale costs about Rs 2.5 more per pipe, and sharp sand about Rs 1,
- FAUP type pipes will cost about 25 per cent less than WASA pipes, and 50 per cent more than small factor pipes,
- the increase in cost for the 1:3:6 and the 1:2:4 pipes is only about 10 per cent and 20 per cent respectively; this is much less than their respective increases in strength,
- despite a 25 per cent rise in the cost of cement, pipe prices have not risen, suggesting that less is being used,
- if sewer pipes are to meet the requirements of BS 5911 pipe prices will have to rise.

Table 3 details some material and pipe costs. It includes improvements to increase existing strength and durability, and alternatives. Some changes would have little impact on cost, e.g. granite aggregate, reduced water:cement ratio, improved curing. Others would have more impact, e.g. more cement and/or reinforcement.

Conclusions

1. The results show that:
   a) there is an urgent need to improve production practices at all pipe factories;
   b) unless a pipe is made of strong concrete the reinforcement is more important for preventing its collapse than increasing its strength;
c) although the cement lining improves pipe durability, using 50 per cent of it in the concrete instead will increase pipe strength, and durability, without increasing costs, the remainder can still be used for lining if required,
d) because the reinforcement is virtually ‘nominal’ it should be feasible to increase pipe strength and durability at no extra cost by reducing the reinforcement and increasing the cement content of the concrete.

2. Sewers which use FAUP type pipes will be stronger and more durable than those which use WASA pipes from normal production or small factory pipes. OPP pipes which are made similarly will therefore be stronger too. However, it has yet to be shown that FAUP pipes, and therefore OPP, WASA or small factory pipes, can be used safely at shallow depths without additional protection against heavy loads.

3. The better performance of the ‘controlled’ pipes is attributable using better quality materials, in the correct quantities, and better quality control. Using a gauge box, a water container of known volume, and curing the concrete in water for seven days, instead of two or three, are all key elements of this process.

4. The cost of using better quality sand and aggregate is very small compared to the improvements achieved.

5. Unless costs can be reduced it will be difficult to promote the use of improved pipes, even if it can be clearly justified technically. It will be necessary work with communities and manufacturers to promote demand for the better pipes, and also find other ways to reduce sewerage costs, e.g. use fewer and smaller manholes.

6. Once improved, e.g. FAUP type, pipes are accepted, increasing their strength by using 1:3:6 concrete should be a relatively easy, cheap and cost-effective improvement. There are fewer benefits in using 1:2:4 concrete.

7. Using the data collected a reduced thickness/capacity manhole cover is feasible in streets up to about 4 m wide. In wider streets the thickness can only be reduced if the manhole diameter is also reduced. Reducing manhole size will also reduce construction costs.

8. Manhole diameters can only be reduced if the smaller size is acceptable to communities and it is still possible to rod the sewers properly.

Recommendations
1. The production of existing pipes must be improved. The cost implications, demand and willingness-to-pay for this should be investigated, and used in promotion to manufacturers, WASA and communities. The structural role of pipes, and the need to make them with appropriate materials and methods, must also be stressed.

(Some recommendations have already been made. It has yet to be decided how they should be implemented.) In particular:

a) WASA should take steps to improve the production of WASA standard pipes, including random testing.

(Recommendations for action forwarded to WASA.)
b) Pipes for non-WASA schemes should be stronger, using at least 1:3:6 concrete. If possible, this should be achieved at no extra cost by using some lining cement in the concrete, and/or reducing the reinforcement. Tests are required to determine the effect of reducing reinforcement and increasing concrete strength.

2. The in-situ test results should be used to recommend minimum cover for all pipes.

3. According to the results of the tests outlined in 1(b) and 2 above, WASA should approve pipe type 1.4, or a modified version (see Table 3), for private and community-based projects (see also Comments below).

4. There should be field trials to determine the appropriateness of 450 mm dia. mass concrete manholes up to 1m deep. There should also be trials of improved hand operated maintenance equipment. If they are satisfactory WASA should approve these manholes for use in private and community-based schemes.

Comments
The original objective of the investigation remains feasible, i.e. recommending a pipe which is economic and appropriate for community-based projects. However, the low concrete strengths of the WASA standard and the small factory pipes, and the poor performance of the WASA standard pipes in particular, have added some unexpected dimensions to the study. Cost has now become more important and less straightforward, with greater implications for WASA and communities, including the willingness-to-pay for improved performance and seeking cost reductions elsewhere. Technical issues have perhaps become less important.

Until more details are available on these matters (see Recommendation 1 above) it remains difficult to make a realistic comparison between the pipes and appropriate recommendations.

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PAUL DEAN, FAUP/GHBC International.