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**DESIGN OF AN EMERGENCY PORTABLE ROUGHING
FILTER USING POLYSTYRENE BEADS AS MEDIA**

by

YORGOS KAPRANIS

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the award of degree of
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Yorgos Kapranis

Supervisor: R A Reed BSc CNA

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ABSTRACT

Roughing filtration is a simple, efficient and chemical free water treatment method for turbidity removal; it can be used as a pre-treatment method prior to slow sand filters or disinfection with chlorine. The main disadvantage of roughing filtration for use in emergency situations is that it uses gravel as a filter medium. Gravel may be unavailable or difficult to transport because of its weight.

Polystyrene beads can replace gravel; they are lightweight and can be expanded on site. Preliminary laboratory studies confirmed that polystyrene beads are effective media and yielded the critical design parameters of 0.75 m/h filtration rate, 0.75 m media depth and 4 mm average media size. This dissertation presents the design and construction of a portable roughing filter using such polystyrene beads as filtering media. The filter is destined for use in emergencies, thus it is designed for ease of transport, low weight, rapid assemblage and simple operation. The filter is designed around a proprietary collapsible water tank and includes a drainage system, flow control, water collection and media. The internal diameter of the filter is 3 m and the nominal flow rate of the filter is 1.47 l/s.

Due to the buoyancy of the polystyrene beads, the structure has to be reinforced to support the upforce produced from the submerged beads; an aluminium lattice secures the beads underwater and a base is designed to reinforce the flexible tank.

The complete filter may be packaged in 2 boxes for ease of transport; the dimensions of each box are 0.8 x 1.2 x 1.6 m, and the total weight of the filter including packaging is approximately 620 kg. In addition, 200 kg (3.4 m³) of unexpanded polystyrene beads are required to complete the filter. Two people are able to construct the entire installation in less than 5 hours.

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EXECUTIVE SUMMARY

In an emergency situation, international aid agencies and non governmental organisations are often asked to provide safe drinking water.

Infectious diseases caused by pathogenic bacteria, viruses and protozoa or by parasites are the most common and widespread health risk associated with drinking water.

The most common source of raw water in emergencies is surface water, which is always considered polluted, containing pathogenic micro organisms. These pathogens are responsible for the transmission of many diseases.

A water related disease is one which is in some way related to water or to impurities in water. Drinking water must be 'treated', i.e. the pathogens must be removed or inactivated.

The priority for water treatment in an emergency situation is to provide safe water in quantities adequate at least for a survival level. Water treatment can be divided in two categories: pre - treatment for the removal of suspended solids and main treatment for the removal of pathogens.

The most common emergency treatment method for drinking water is disinfection with chlorine generating products; slow sand filtration is an alternative method for pathogen removal.

Efficient application of disinfection and/or slow sand filtration requires raw water of low turbidity, preferably < 20 NTU (Davis and Lambert 1997). Pre-treatment of raw water containing solid matter is therefore necessary. One common pre - treatment method in emergencies is chemical flocculation in conjunction with sedimentation for solid matter separation. However, the use of chemicals increases the reliance on technical expertise and external agencies for the continuation of effective water treatment after the emergency has passed. In addition, such treatment methods can often not be integrated into a rural treatment plant after the emergency because of

the unavailability of chemicals, inadequate dosing equipment, difficult operation and maintenance procedures, or lack of local technical skills and trained operators.

Although coagulation and flocculation are valuable in the beginning of an emergency, various authors recommend to replace them as soon as possible with other methods of turbidity reduction

An alternative is prefiltration using roughing filters which are simple, efficient and chemical free. It also can be used by local agencies or authorities after the emergency has passed. Practical experience shows that roughing filters can achieve a particulate matter reduction of 90% or more (Wegelin 1986); furthermore, they can improve the bacteriological water quality (i.e. a 1 -2 log reduction of faecal coliforms has often been recorded), and reduce colour and dissolved organic matter to some extent.

In an upflow roughing filter water flows at low velocity through a coarse medium in an upward direction. The filter bed is sometimes composed of material decreasing in size in the direction of the flow and others of media of a constant size. The basic components are the filter box which contains the media, the media bed, the underdrain system, the inlet and outlet construction and the flow control devices.

Mechanical, physical, biological and chemical processes are all solid-removal mechanisms in roughing filtration (Wolters et al., 1989). Filter design is defined by six design variables which can be selected within a certain range: filtration rate, average size of filter medium, individual thickness of filter medium, number of filter fractions and area of filter bed. Any inert, clean and insoluble material can be used as filter medium as long as it has a large specific surface and high provides a bed of high porosity.

The principal disadvantage of roughing filters in emergencies is the filter medium which is commonly gravel. Graded gravel media are not necessarily available in situ and may need to be graded and transported over long distances. Gravel is bulky, heavy and difficult to transport to remote locations.

Polystyrene beads can provide an alternative medium. It is lightweight and can be transported in a compacted state and expand on site, thus eliminating the logistical

problem of the gravel supply. Experimental work in WEDC comparing polystyrene beads to gravel in roughing filtration showed that polystyrene beads are as effective as gravel for turbidity removal; the experiments with a pilot upflow roughing filter have shown that upflow roughing filtration with polystyrene beads of 4 mm diameter, a filter thickness of 0.75 m and a filtration rate of 0.75 m/h can remove turbidity up to 90% in some cases (Reed and Kapranis, 1998)

This report presents the design and construction of a portable roughing filter using polystyrene beads as filtering media. The filter was designed and constructed as a kit, so that it can be easily transported and assembled in an emergency.

The design and construction of the various components of the filter are presented in detail in the order of the actual construction.

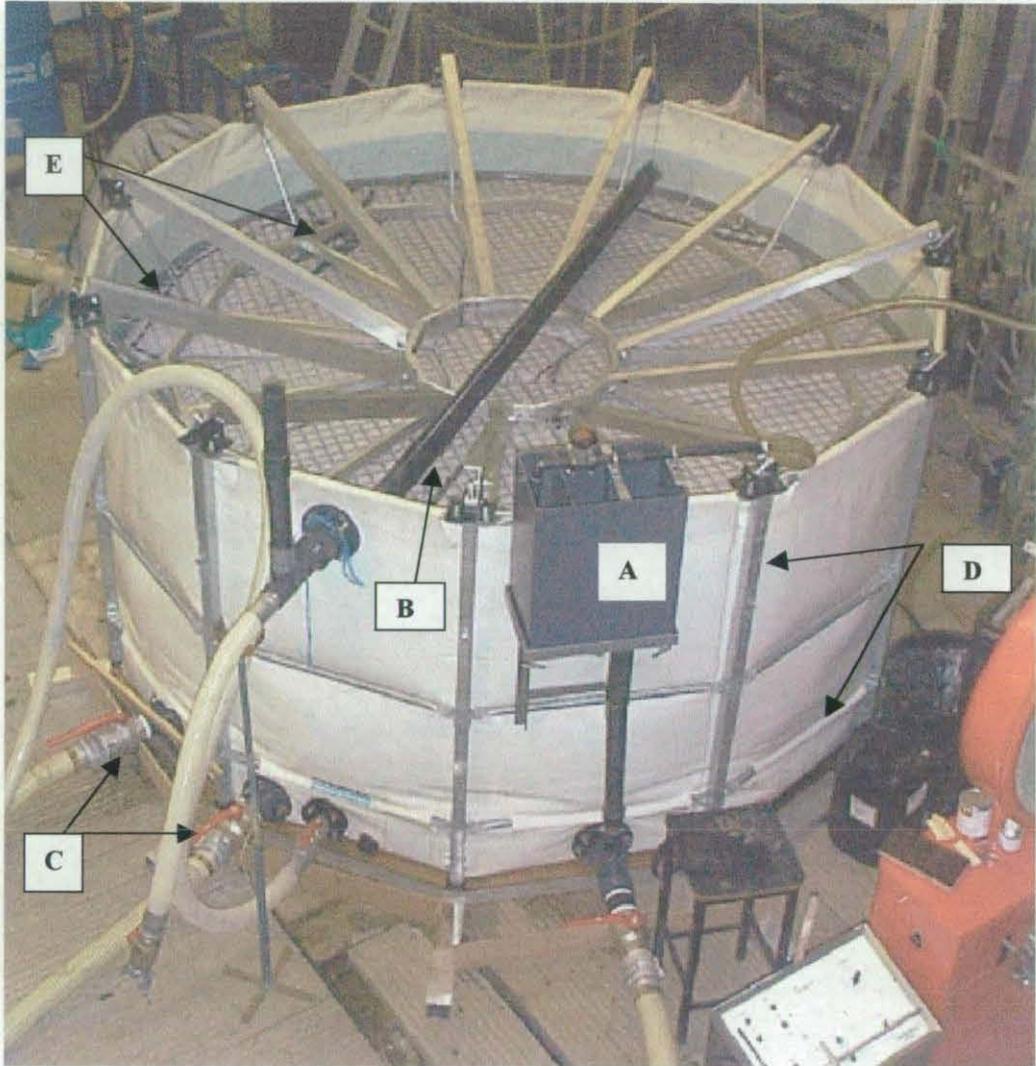
The filter is designed around a collapsible water tank; the main components of the filter are the drainage system, the water collection system, and the flow control at the inlet; the media are placed on a raised floor to facilitate the drainage process.

The polystyrene beads are enclosed in bags made out of fishing net; the buoyant beads are being held down by an aluminium lattice which is attached to the tank's iron reinforcing frame; the iron frame is then attached to a base in order to avoid the beads lifting the tank's sides.

The flow is controlled with a box containing a V - notch weir. The water is evenly distributed in the filter through a system of perforated pipes. These pipes also serve as part of the drainage system. The water is collected on the top of the filter through a perforated pipe.

The overall performance of the kit is deemed satisfactory. The structural, hydraulic and overall performance are satisfactory; the only exception is the flow control which requires more work.

The filter can be seen in Picture 1.



- A: Flow Control Box
- B: Water Collection Pipe
- C: Rapid drainage valves
- D: Iron frame for erecting water tank
- E: Aluminium lattice for restraining media

Picture 1: Portable roughing filter

NOMENCLATURE & ABBREVIATIONS

COD Chemical Oxygen Demand

DFRF Down Flow Roughing Filter

HFRF Horizontal Flow Roughing Filter

NGO Non Governmental Organisation

NTU Nephelometric Turbidity Unit

UFRF Up Flow Roughing Filter

UNHCR United Nations High Commission for Refugees

WEDC Water Engineering and Development Centre

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CHAPTER 1

INTRODUCTION

A disaster results in a serious disruption of society, causes widespread human suffering and physical loss or damage, and stretches the community's normal coping mechanisms to breaking point. The term emergency is used to describe the crisis that arises when a community has great difficulty in coping with a disaster. External assistance is needed, sometimes lasting for many months, perhaps years (Davis and Lambert 1996).

Safe water is essential to life and health. The provision of water requires immediate attention from the beginning of an emergency.

People who are affected by an emergency often only have access to surface water which is rarely pure. It often contains many pathogenic organisms. In an emergency, the affected population is frequently vulnerable and diseases can reach epidemic proportions very fast.

The use of surface water requires treatment measures in order to remove the pathogens. The most common techniques which are used in emergencies for removal of pathogens are chlorination, and to a lesser extent slow sand filtration. Both of these techniques require water which is relatively free of solids and impurities.

Chemical coagulation and flocculation is the most common technique for the removal of suspended solids in water. Its disadvantage is that it relies on chemicals, which can be hard to find, need supervision for storage/application and require a safe disposal of the generated sludge.

Roughing filtration is a chemical free alternative for solids removal; it has been widely used world wide with success. Water is treated by passing through a gravel medium. Roughing filters use simple technology combined with physical, chemical and biological processes to remove solids and impurities.

The main disadvantage of roughing filters in emergencies is that it takes too long to construct; in addition, the use of gravel as medium may be problematic since it can be hard to find or even unavailable. It is also bulky, heavy and difficult to transport.

Previous research in the Water, Engineering and Development Centre (WEDC) using various pilot filters containing different types of polystyrene beads and gravel, has shown that polystyrene beads can successfully replace gravel as filtering media. These beads have the advantage that they are very light when compared to gravel.

In addition, further research in WEDC has produced a low cost expansion machine designed around a 200l metal drum; it can expand the compacted beads by immersion in boiling water; this machine could be easily transported together with the beads on site.

The next logical step of the research was to examine whether a roughing filter could be constructed using the polystyrene beads as media. If this filter could be built as a mobile unit, then it could be dispatched on site together with the beads and the expansion machine and become operational in a matter of hours.

When the author accepted the responsibility to design a mobile roughing filter, he had already worked in various emergencies where the provision of potable water was of the utmost importance. Having always relied on chemicals for assisted coagulation and flocculation, he was in a position to appreciate the advantages of roughing filtration. After a thorough literature review in order to understand the mechanisms of roughing filtration and existing work on the subject, he began the design process. Since the potential users of the filter would be individuals working in emergencies, these users would need a reliable, lightweight yet robust, easy to transport, set up and operate filter. Thus the design advanced trying to satisfy these needs.

The research objective of this thesis is to design a portable roughing filter using polystyrene beads as media which will be capable of rapid dispatch and installation in the field. This is done by reviewing previous work in chapters 2 to 3 regarding the use and design of roughing filters; the design concept is presented in

chapter 4, from which detailed design of components is presented in chapter 5; a prototype was built to the design and the results are presented in chapter 6. Finally, the conclusions of the project and the recommendations for future work are presented in chapter 7.

2.1 WATER RELATED DISEASES

'Safe drinking water is important in the control of many diseases ... it has been estimated that as many as 80 % of all diseases in the world are associated with unsafe water' (IRC, 1983).

Safe water is essential to life and health. When water is not available, dehydration will occur very quickly and death will certainly follow. If water is not available in sufficient quantity and quality, infectious diseases will have a direct impact on a population's health.

There are many diseases which are related to water. One category is the *water washed diseases*, where the transmission of many infections of the intestinal tract and of the skin depends on the lack of water used, rather than the quality.

One other category is the *water borne diseases*, where the transmission occurs when the pathogen is in water which is drunk by a person or animal which may then become infected. Potentially water borne diseases include cholera and typhoid, infectious hepatitis, diarrhoeas and dysenteries.

Finally, in the *water based diseases*, a pathogen spends a part of its life cycle in a water snail or other aquatic animal. An example is schistosomiasis, where water polluted by excreta contains aquatic snails in which the schistosome worms develop.

All the water - borne and water - washed diseases, as well as most of the water based diseases and several others not related to water, are caused by pathogens transmitted in human excreta, normally in the faeces (Cairncross & Feachem 1993); these diseases can be controlled by improvements in sanitation, hygiene and the quality and quantity of water supply.

2.2 DRINKING WATER QUALITY

Standards in drinking water quality are expressed in terms of the microbiological, chemical, and physical characteristics of the water (Cairncross and Feacham 1993).

The microbiological quality of drinking waters is typically expressed in terms of the concentration and frequency of occurrence of particular species of bacteria. Faecal coliforms are the most commonly used. They occur almost entirely in faeces and their presence in water is therefore indicative of faecal contamination of that water.

Although there are no set rules as to the acceptable quality for potable water, certain guidelines have been set down for chemical and physical water quality criteria by the World Health Organisation (WHO 1993). Some guideline values are based on health criteria and most are related to long term consumption; i.e. the presence of arsenic in groundwater . Others are based on aesthetic concerns such as colour, taste and smell which might lead the user to alternative, but potentially less safe source; for example, iron and manganese may cause groundwater to be coloured and although they do not represent a health hazard people may prefer using contaminated surface water because it is palatable and not coloured.

It is therefore advisable to ensure that the drinking water is not only pathogen free but that it has properties which are acceptable to the user population as well.

A safe and potable drinking water should conform to the following water quality characteristics:

- Free from pathogenic organisms
- Low in concentrations of compounds that are acutely toxic or that have serious long term effects
- Clear
- Not saline
- Free of compounds that cause any offensive taste or odour

- Non corrosive, nor should it cause encrustation of piping or staining of clothes (Schulz and Okun 1992)

The choice of the water source can influence the water quality; in an emergency situation, many potential problems can be prevented by carefully choosing the water source. In order to understand the characteristics of the various sources and their influence on water quality, the possible water sources must be presented.

2.3 WATER SOURCES

From their origin point of view, there are three main sources of natural water: surface water, ground water and rainwater (UNHCR 1993).

- Surface water is water from streams, rivers, lakes, dams and reservoirs. A typical sample can contain many different materials, ranging from very large elements such as floating solids (wood, leaves) down to sub - micron size particles such as bacteria and viruses.

Flowing surface water such as streams and rivers is often subjected to extreme quantitative and qualitative changes (Wegelin 1996); they will carry solids at various concentrations during different periods of time. For example, heavy rainfall may result in short term peaks of the solids.

In impounded surface water sources such as lakes and reservoirs, the amount and type of solid matter will change only gradually in the course of the year because solids settle slowly under the influence of gravity to the bottom of the lake.

Surface water must always be assumed to be contaminated. It may be used in emergencies only when there is no alternative source (UNHCR 1993); the reason is that it may be difficult to remove high concentrations of solids and pathogens.

- Rainwater can be collected from the clean roofs of buildings and tents; this method requires an adequate and reliable year - round rainfall, suitable shelters and household storage facilities. It can not be considered a solution in an emergency situation (UNHCR 1993). Nevertheless, it can sometimes be used as a short term measure.

- Groundwater is water underground that fills the natural openings in rock and sediments. If there is no underground contamination, groundwater is in most cases pathogen free and free of chemicals. Groundwater is the preferred source of water because if available, it usually provides the most cost - effective alternative for the necessary quantity and best quality of water. The quantity of groundwater can be influenced by seasonal variations; it is therefore necessary to study all the factors regulating the recharge, transmission and release of water.

Springs are the most important natural groundwater discharge. They are usually a source of high quality water; they must be preserved by protecting the spring from pollution. The protection may require a lot of work, so spring water can not be immediately available in an emergency.

One other method of abstracting groundwater is digging a hole to below the water table. This method may require a lot of work; in addition, the yield of the water may vary significantly throughout the year. Groundwater exploration can take a long time before it can be confirmed that there will be a sufficient quantity of water throughout the year; in addition, special equipment may be required in the exploration for new groundwater sources (UNHCR 1983). Due to these reasons, the use of groundwater in emergencies is not recommended as an initial response unless the wells already exist.

It can be concluded that in emergencies surface water is the source which is readily available in most situations. Water quality is always difficult to assess; it must be assumed that all water available during an emergency is contaminated, especially surface water (UNHCR 1992). Since surface water must be always considered contaminated, the pathogens must be removed, i.e. the water must be *treated*. Before discussing the various treatment methods in emergencies, some basic principles of water treatment will be explained.

2.4 WATER TREATMENT

The term '*water treatment*' can be defined as the removal or inactivation of pathogens (Wegelin et al. 1991).

As it has already been explained, surface water may contain a large range of solids. Micro-organisms such as pathogens may use the solids as 'carriers' which may protect them from the effects of a treatment process. Consequently, water treatment must also remove the solids from the water.

Water treatment can be a complex process because the removal or inactivation of such a wide variety of particles may demand more than one treatment stage. The *multiple barrier principle* of water treatment states that the water suppliers who rely on treatment systems with only one or two stages take a higher risk of breakdown, and thus breakthrough of contaminants, than suppliers who incorporate a series of complementary processes in water treatment plants (Wheeler 1988).

Galvis et al. (1993) also recommend the multiple barrier principle and quote Okun that " ... the first barrier is selecting and protecting the best available source. This is far more economical and effective than allowing developments to occur in the water shed area and rely subsequently on advanced treatment..."

In developing countries, a large number of people are forced to use surface water from polluted rivers, lakes, ponds and irrigation canals. Since this water is a carrier of many diseases it should be treated prior to consumption (Wegelin et al. 1991). During the first days of an emergency, people will tend to use surface water because it is usually readily available. Groundwater from springs and wells may also be used, but it is less common and may be insufficient for a large group of people.

Water supply and treatment in an emergency situation can not be approached in the same way as in a rural / urban water supply and treatment. 'People can survive longer without food than without water... the provision of water demands immediate attention ... the aim is to assure availability of enough water to allow sufficient distribution and to ensure that it is safe to drink' (UNHCR 1992). An assistance program to a population should provide ample supply of safe and wholesome water to the beneficiaries. In general terms, a large quantity of reasonably safe water is preferable to a smaller amount of very pure water.

The use of water treatment should be restricted to those situations where such treatment is absolutely essential and where correct plant operation and maintenance can be secured and verified (UNHCR 1992).

Treatment processes are generally classified in two main stages: pre - treatment and main treatment.

An extra stage can be advanced treatment, which may be used to reduce chemical pollutants. Some examples of available techniques are reverse osmosis, filtration through activated carbon, chemical precipitation etc. These techniques are often inappropriate for developing countries and emergencies in particular. "As enteric diseases are the predominant health hazard arising from drinking water in developing countries, standards for water quality should concentrate on microbiological quality... the removal of many chemical constituents from drinking water requires sophisticated treatment processes that are beyond the technical and financial capabilities of most communities in the industrialised countries" (Schulz and Okun 1992).

Even though water treatment technology in emergencies should be kept simple, it can be a complicated process, depending on the raw water characteristics. In order to fully understand the concept of water treatment, the most common treatment techniques will be presented in the following section of this paper. These methods are not necessarily applicable only in emergencies, but in rural water supply as well.

2.4.1 Pre - treatment

The aim of pre - treatment is to remove suspended solids in turbid water so that subsequent treatment to remove pathogens can be effective. Pre - treatment can also improve the potability of water and its acceptance by the consumers by removing unpleasant tastes. The mechanisms are mainly physical. Some pre - treatment steps are the following:

2.4.1.1 Abstraction

Abstraction is the first stage in a treatment process. At the very least, it should prevent the inflow of large solids and silt. The use of screens and gabions can prevent

such inflow. Practically all intakes are screened, even if the screens may be of the simplest type of bar grill (Twort et al. 1994).

It is well known that when water passes through layers of gravel and sand, its quality can improve dramatically. This action is better known as filtration. When the hydrogeological conditions are favourable, water can be abstracted from a river or a lake via a nearby shallow well. In that case, the natural bank material is used as a filter. If the soil of the river bank is impervious, the natural purification capacity can be exploited by constructing infiltration galleries and wells. The infiltration gallery is a pipe surrounded by gravel leading to a bankside well (fig 1). Water from the lake or river infiltrates through the layers of gravel and passes to the well through perforated pipes.

The water that can be abstracted using the previous methods can be of low or minimal turbidity, depending on the effectiveness of filtration.

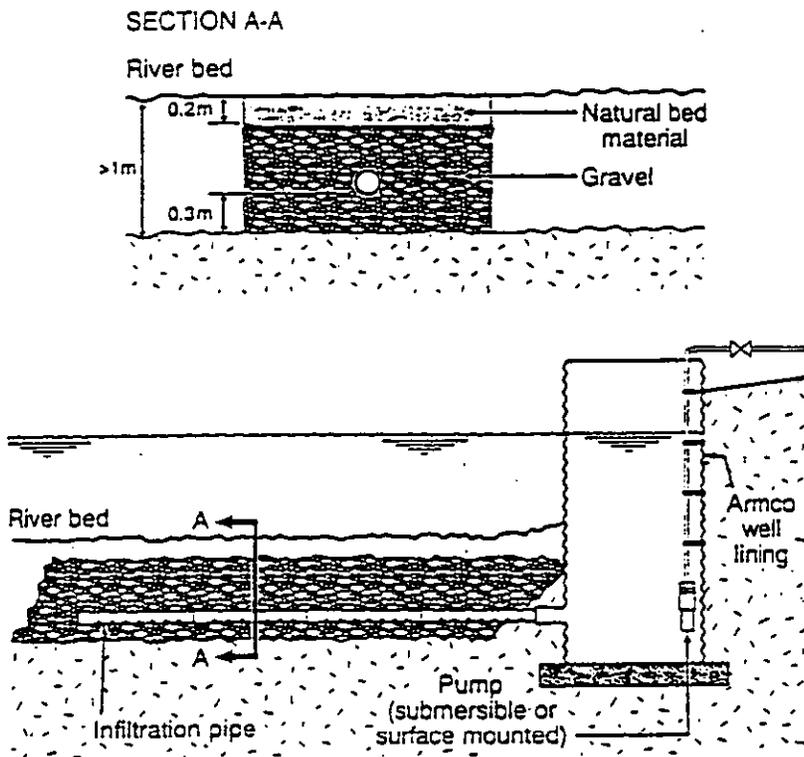


Fig 1 : Infiltration Gallery

Source : *Davies & Lambert (95)*

2.4.1.2 Storage

Storage has a double role: it provides a reserve supply of water and also acts as a form of treatment (Davies and Lambert 1995). Stored water undergoes a complex combination of physical, chemical and biological changes. According to Twort et al. (1994), raw water storage has traditionally been regarded as a major or essential first line of defence against the transmission of water borne diseases.

During storage, some of the suspended solids will settle under the influence of gravity, thus reducing turbidity (Davies and Lambert 1995). This phenomenon is called natural sedimentation. Since pathogens may be associated with the solids, the removal of a fraction of the solids will result in the removal of some of the pathogens thus improving the water quality. Some pathogenic micro organisms also die if the water is left undisturbed in reservoirs due to starvation and predation (WHO 1993).

It is recommended to provide maximum storage capacity at refugee sites at the onset of an emergency assistance. For a substantial improvement in water quality, storage should be for at least 12 to 24 hours; the longer the period of storage and the higher the temperature, the greater the improvement; storage periods of up to two weeks are recommended for maximum improvement in water quality (UNHCR 1992).

During periods when the raw water is of high turbidity or there is unusual pollution in the water source, storage can also provide water for the next stage of treatment until the raw water quality improves.

One possible disadvantage of storage can be the growth of various forms of aquatic plants and free floating algae which may increase the difficulties of treatment (Twort et al. 1994); this problem can be prevented by covering the tanks to exclude sunlight.

Storage is of limited use in emergencies when a large quantity of water is needed, because the cost of reservoirs large enough for storing an adequate quantity of water can be high.

2.4.1.3 Sedimentation

Sedimentation can be defined as the settling and removal of suspended particles that takes place when water stands still in, or flows slowly through a basin. Due to the low flow, turbulence will be absent or negligible and particles having a mass density greater than water's will settle under the influence of gravity (IRC 1983).

The efficiency of the process is measured by turbidity removal and is largely dependent on the size of the suspended particles and their settling rate. Fig 2 shows particle diameters and settling ranges for suspended material found in water (Schulz and Okun 1992). It is obvious that in emergencies, plain sedimentation is of no practical importance for the removal of particles of 0.01 mm or less, since the time required to settle would be many hours.

Although sedimentation can take place in any basin, settling tanks specially designed for sedimentation are used in treatment plants. Horizontal flow, rectangular tanks are generally used in small treatment plants because they are simple to construct and adequate. The raw water enters the tank and the particles are removed in the settling zone; the settled particles are deposited on the bottom of the tank and form a sludge layer (IRC 1983). These tanks operate continuously. The design of a typical rectangular horizontal flow settling tank can be seen in fig 3.

In emergencies, it may not be possible to construct purpose made sedimentation tanks; as an alternative, several temporary storage tanks can be used on a rotational basis and the sludge must be removed periodically; this process is known as a batch system (Davis & Lambert 1995).

Diameter of Particle (mm)	Order of Size	Total Surface Area ^a	Time Required to Settle ^b
10	Gravel	3.14 cm ²	0.5 sec
1	Coarse sand	31.4 cm ²	3 sec
0.1	Fine sand	314 cm ²	36 sec
0.01	Silt	0.314 m ²	33 min
0.001	Bacteria	3.14 m ²	55 hr
0.0001	Colloidal particles	31.4 m ²	230 days
0.00001	Colloidal particles	0.283 ha	6.5 yr
0.000001	Colloidal particles	2.83 ha	63 yr minimum

^a Area for particles of indicated size produced from a particle of 10 mm in diameter with a specific gravity of 2.65

^b Calculations based on sphere with a specific gravity of 2.65 to settle 30 cm

Fig 2: Particle size vs. settling rate

Source: Schulz & Okun (92)

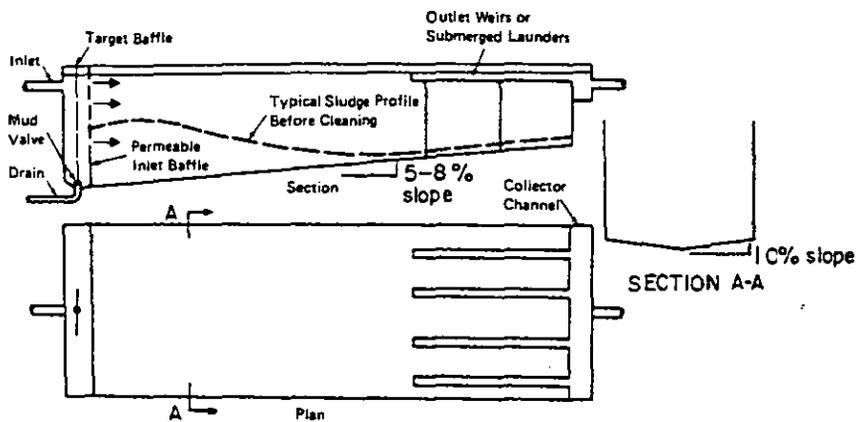


Fig 3: Rectangular horizontal flow settling tank

Source: Schulz & Okun (92)

2.4.1.4 Aeration

Aeration is widely used for the removal of taste and odour as well as the removal of iron and manganese. The atmospheric oxygen brought into the water through aeration will react with the dissolved ferrous and manganous compounds changing them into insoluble ferric and manganic oxide hydrates. These can then be removed by subsequent treatment processes such as plain sedimentation or filtration. The removal of tastes and odour is of particular importance for the organoleptic acceptance of the treated water.

When water is brought into intimate contact with air, the action on water is:

- the bad tastes and smells are reduced
- iron and manganese are precipitated from solution
- water aggressivity is reduced and pH is raised
- the dissolved oxygen of the water is increased

Various arrangements for aeration maximise the air / water contact surface area and contact time. When there is sufficient head, the water may fall down a cascade of steps or perforated tiles; this type is known as *cascade aerator*. In *tray type aerators*, water falls from one perforated tray to a lower perforated tray. Other types of aerators are the spray aerators, where the water is sprayed through nozzles into a collection tank. Tray aerators are the most commonly used; fig 4 shows a simple tray aerator.

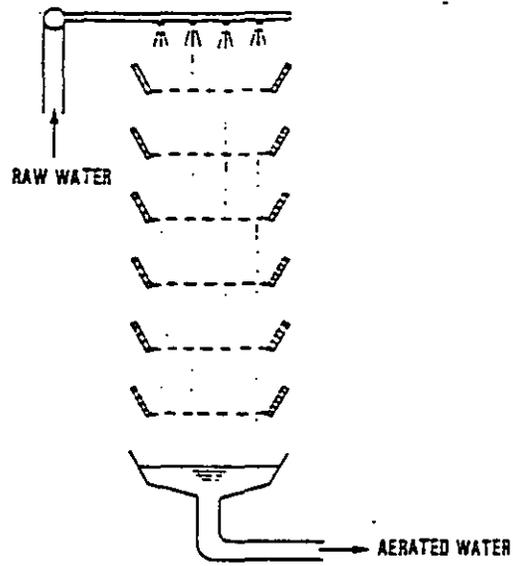


Fig 4: Tray aerator

Source: IRC (83)

2.4.1.5 Coagulation and flocculation

As it has already been mentioned for plain sedimentation, small particles such as colloids can take a very long time to settle (fig 3). Colloids are kept in suspension by electrostatic repulsion and hydration. Electrostatic repulsion usually occurs because colloids have a surface charge due to the presence of a double layer of ions around each particle; the colloid has a surface charge, mostly a negative one. Hydration is the reaction of particles at their surface with the surrounding water; the resulting particle - water agglomerates have a specific gravity which differs little from that of water itself (IRC 1983).

Certain chemicals, which are called coagulants, have the capacity to compress the double layer around the particles. Once the electrostatic repulsive forces are suppressed, weak mass attraction forces (Van der Waals forces) bring the particles together in order to form 'flocs'. The flocs can grow to a sufficient size and weight which will allow them to settle

The terms coagulation and flocculation are sometimes used with the same meaning; it is suggested that it is probably more correct to use the former to mean the first stage in the formation of a precipitate and the latter to consist of the building up of particles of floc to a larger size which can be removed in a subsequent treatment process (Twort et al. 1994).

The most common metal coagulants are based on aluminium and to a lesser extent iron (Schulz and Okun 1992). The most common one by far is aluminium sulphate, commonly known as 'alum' (IRC 1983). The dosage of metal coagulants depends on factors such as pH, turbidity, chemical composition of the water, type of coagulant, temperature and the mixing conditions).

Synthetic coagulants such as polyelectrolytes are the new generation of coagulants. Some of their advantages when compared to metal salts are their effectiveness over a wide pH range, the requirement of a low effective dosage and the production of lower sludge volumes (Lambert and Davies 1995).

Natural coagulants have also been traditionally used for many centuries in developing countries. At the same time, they have been proven effective in community water treatment plants, based on practical experience in Great Britain, India, Sudan and other countries. Some examples of these natural coagulants are the seeds of *Moringa Oleifera* and *Strychnos Potatorum* trees (Schulz and Okun 1992).

Coagulation and flocculation are widely used in emergencies for solid matter separation. In an emergency situation, coagulation has the advantage of very rapid installation, provided the chemicals are available; however, because of the process's reliance on chemicals and associated problems of safe sludge disposal, it is recommended to replace it with other methods of turbidity reduction as soon as possible (Davies and Lambert 1995).

Other authors discourage the use of coagulation and flocculation. According to IRC (1983), 'chemical coagulation and flocculation should only be used when the needed treatment result cannot be achieved with another treatment process using no chemicals'.

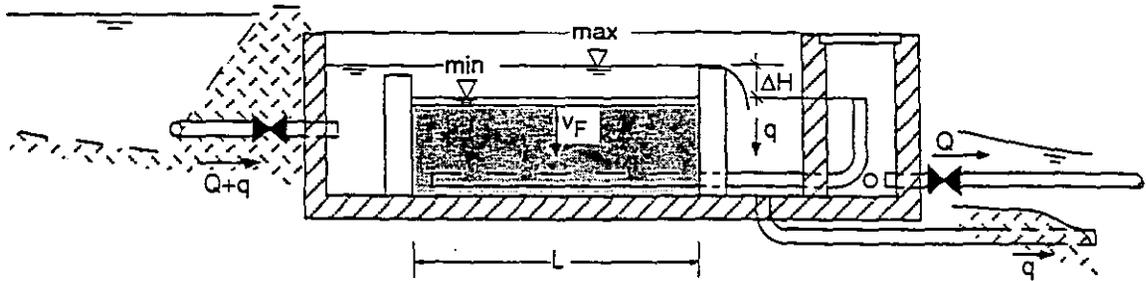
2.4.1.6 Pre - filtration

Pre - filtration is the removal of suspended solids by the passage of water through relatively coarse media (5 - 25 mm). The term prefilters can be used to define the filters used in pre - treatment as opposed to filters used in main treatment.

Design and application of prefilters vary considerably. Intake and dynamic filters are usually the first components of a treatment scheme. They are similar to infiltration galleries and usually are part of the intake structure. Intake filters are used as first treatment step, mainly for solids separation. Dynamic filters are used to safeguard the treatment plant from sudden solids concentration peaks. Since the separation of solids takes place usually within the inlet zone of the filter, they function as surface filters. They are cleaned manually by scouring the top of the filter with a shovel or a rake. A general layout of intake and dynamic filters is given in fig 5.

Roughing filters are generally located at the treatment plant. The main difference from dynamic and intake filters is that roughing filters are used for turbidity reduction,

generally as the last pre - treatment step prior to the main treatment. Since this paper is about the design of a portable roughing filter, roughing filters will be presented in more detail in chapter 3.



list of symbols

d_g	(mm)	gravel size
L	(m)	filter length
W	(m)	filter width
A	(m^2)	filter area
ΔH	(cm)	headloss
Q	(m^3/h)	flow rate
v_F	(m/h)	filtration rate
q	(m^3/h)	surplus flow rate

design guidelines

filtration rate

$$v_F = \frac{Q}{L \cdot W} = \frac{Q}{A}$$
 max. headloss (operation)
 ΔH

gravel size

	$d_g = 2 - 4 \text{ mm}$
	$d_g = 4 - 8 \text{ mm}$
	$d_g = 8 - 12 \text{ mm}$

intake filter dynamic filter

filtration rate	0.3 - 2 m/h	> 5 m/h
max. headloss (operation)	-20 - 40 cm	-20 - 40 cm
gravel layer height	—	20 - 30 cm
	30 - 40 cm	10 cm
	(10 - 20 cm)	10 cm

Fig 5: Intake and dynamic filters

source : *Wegelin (96)*

2.4.2 Main treatment

The aim of the main treatment is to reduce bacteriological contaminants and/or further reduce turbidity (House and Reed 1997). After the main treatment, the water is considered to be safe for consumption.

As in pre - treatment, there are numerous processes available. The most common ones used in emergencies are disinfection and slow sand filtration.

2.4.2.1 Disinfection

The term disinfection is used to mean the destruction of infective organisms in water to such low levels that no infection of disease results when the water is used for domestic purposes including drinking (Twort et al. 1994).

Although the aforementioned pre - treatment processes such as storage, sedimentation, coagulation and roughing filtration reduce the pathogens in water because they are associated with the separated solids, they can not guarantee that the water is bacteriologically safe. Final disinfection will be needed (IRC 1983).

Although various chemicals such as iodine and oxidants such as ozone have been successfully used, chlorine gas and chlorine compounds are the most widely used disinfectants around the world. The reasons for their universal use are their ability to “kill” pathogenic organisms, to maintain a residual in the distribution system, the world wide availability and moderate cost (Schulz and Okun 1992).

When added to water, chlorine reacts to form hypochlorous acid and hypochlorite ions; they are both powerful bactericides and are together known as *free available chlorine*. Of the two, the former is more effective as a disinfectant than the latter.

Chlorine also reacts with ammonia in water and forms chloramines which also have disinfecting properties and are known as *combined available chlorine*. The various chloramines also have different disinfecting properties.

Part of the chlorine applied will also oxidise other constituents in the water; this quantity of chlorine is known as *chlorine demand*. (Twort et al 1994).

The principal factors influencing the disinfection of chlorine are free residual concentration, contact time, pH and water temperature (Twort et al. 1994):

- the term *free residual* means the amount of free chlorine remaining after the disinfection process has taken place
- an appropriate time is needed for successful chlorination, called *contact time*; after that time period, there should be a sufficient amount of *free available chlorine*; WHO (93) recommend 0.5 mg/l of free available chlorine after 30 min of contact time at pH = 8 and a temperature of 20°C
- disinfection is more effective at low pH values because at low pH the more effective disinfectants in free and available chlorine are formed in greater quantities, at high pH (>7) a greater contact time is required
- by lowering the temperature, there is an important decrease in disinfecting power and the contact time has to increase; the higher the temperature, the more rapid is the kill (Fair et al, 1968)

A pre condition for effective chlorination is low turbidity of the water to be treated. The particles of suspended matter in water may protect the bacteria from the oxidising capacities of chlorine. It is thus always necessary to apply disinfection with chlorine as a final stage (Twort et al. 1994). Hence the importance of having one or more pre - treatment processes for turbidity removal before chlorination.

Chlorination kills bacteria and most viruses but not cysts at standard doses. If turbidity is less than 1 NTU (Nephelometric Turbidity Unit), pH is less than 8, the contact time is 30 min at 20°C, and the free residual chlorine is 0.5 mg/l, then the majority of viruses are killed (WHO 1993).

Chlorine can also be injected into the raw water right after its abstraction; this is called 'pre - chlorination'. It is used in water with a high bacteria content, but low turbidity; it can also be used to oxidise organic matter, iron and manganese as well as reduce colour and slime formation. It can also kill algae. It must be emphasised that pre - chlorination is used as a pre- treatment method, not disinfection; only post - chlorination before distribution can ensure complete disinfection (UNHCR, 1992).

Disinfection with chlorine is the most common main treatment method in emergencies. As it has already been mentioned, a pre condition for chlorination is low turbidity of the water. Turbidity of less than 5 NTU is recommended in an emergency water supply; chlorination however will function relatively effectively up to 20 NTU, but turbidity should be reduced as soon as possible with some pre- treatment process (Davies and Lambert 1995).

2.4.2.2 Slow sand filtration

A slow sand filter (SSF) is a structure containing a bed of fine, graded sand; the water enters at the top, passes slowly through the sand bed and gets collected at the bottom of the filter by an underdrainage. The name 'slow' is due to the slow filtration rate of 0.1 to 0.2 m/h. A basic drawing of a SSF including its basic components can be seen in fig 6.

Slow sand filters act by a combination of both straining and microbiological action (Twort et al. 1994). The term straining means that particles bigger than the sand's pore size can not enter deep in the filter bed. The biological action is due to a biological layer of organic and inorganic material, known as 'Schmutzdecke'; this layer is formed on the top of the sand bed and bacteria and other micro-organisms grow in it. These micro-organisms break down the pathogens in the incoming water by feeding on them and by complex chemical reactions.

It is very important not to chlorinate the water before it passes through the filter, otherwise the chlorine will destroy the biological layer.

The filter is cleaned by removing the top layer of sand (12 - 25 mm); the interval between cleanings may vary from several months during winter when some

form of prefiltration exists to 10 days when no prefiltration and algal growth is at a maximum (Twort et al. 1994).

One drawback of SSF is its sensitivity to turbidity. Turbid water with heavily loaded suspended solids will rapidly clog the sand bed's surface; influent turbidity has to be less than 20 NTU, otherwise the water has to be pre - treated (Davies and Lambert 1995).

SSF remove or "kill" the great majority of viruses, bacteria, protozoa cysts and helminth eggs. In emergencies it is nevertheless recommended to chlorinate filtered water just before distribution as an additional precaution. The following table presents the typical performance characteristics of SSF.

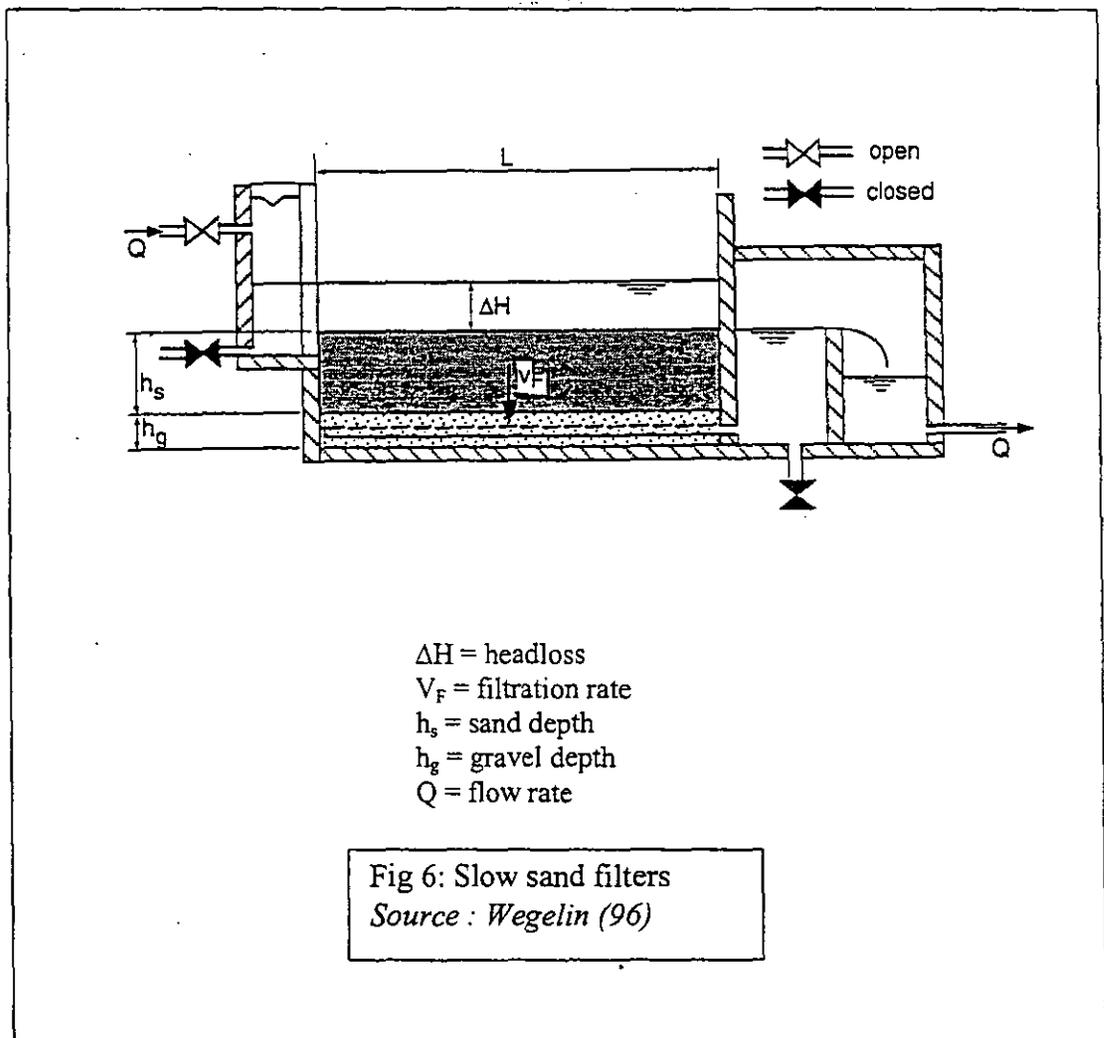


Table 1: Typical Performance Characteristics of Slow Sand Filters

Parameter of water quality	Characteristic
Colour	30 - 100 % reduction
Turbidity	Turbidity is generally reduced to less than 1 NTU
Faecal coliforms	Between 95 - 100 % and often 99 - 100 % reduction
Cercariae	Almost 100% removal of cercariae of schistosoma, cysts and ova
Viruses	Virtually complete removal
Organic matter	60 - 75 % reduction in COD
Iron and manganese	Largely removed
Heavy metals	30 - 95 % reduction

Source: IRC (1983)

2.5 MOBILE PACKAGE WATER TREATMENT UNITS

Water treatment units are small water treatment systems which are designed as mobile units, i.e. they can be rapidly transported and installed on site. They are used in the early stages of an emergency to provide the affected population with a minimum amount of safe water for drinking purposes, as well as for medical and nutritional infrastructures. They are commonly used for a few months until a permanent treatment system is installed.

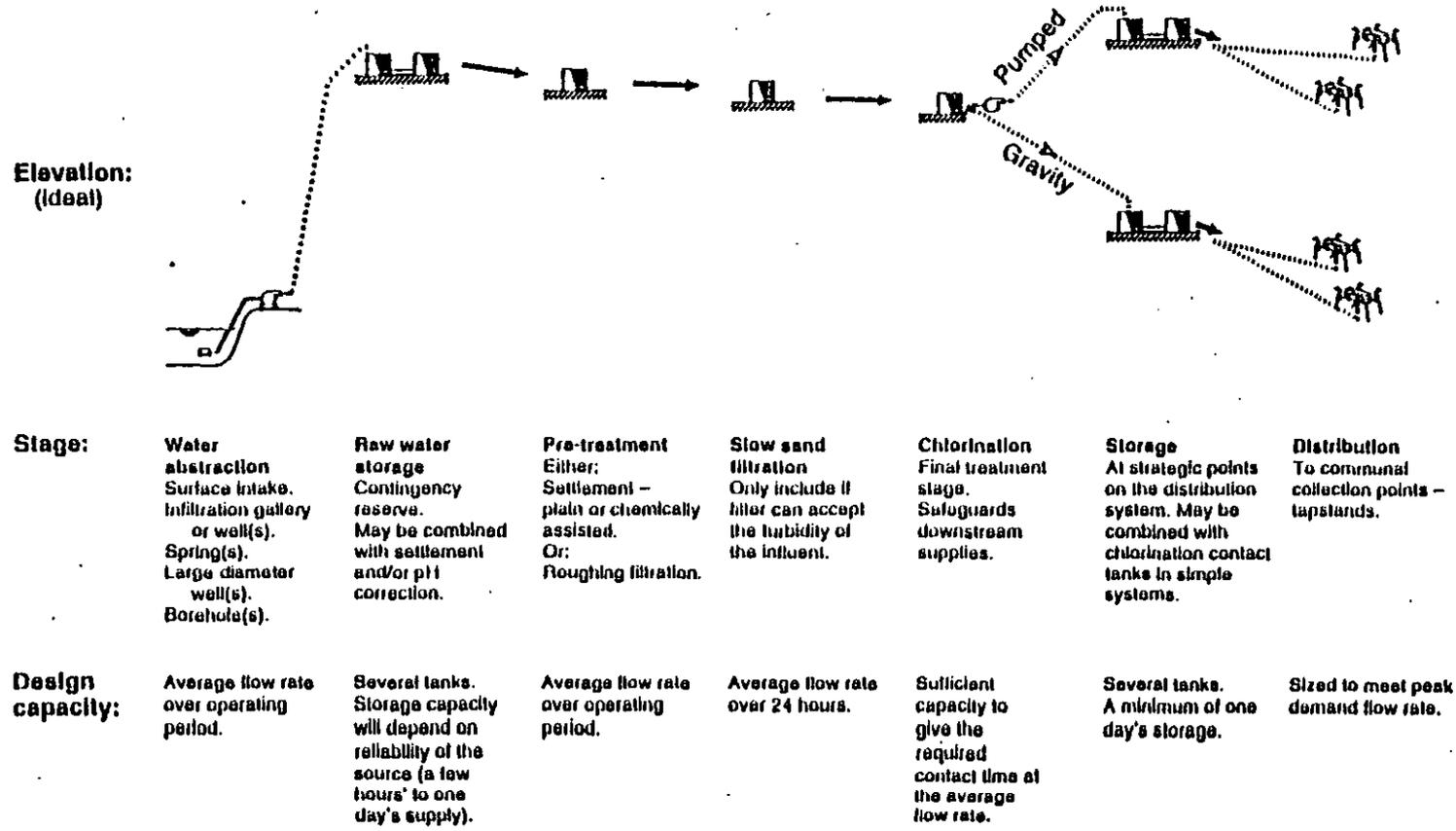
There are a number of water treatment units commercially available which are used by various organisations in emergencies. The cost of such units is quite important, ranges from \$3000 to \$ 87000 (Nothomb 1995).

The disadvantage of such units is that they almost invariably require the use of machines (generators, motor pumps) and chemicals (coagulants, disinfectants); in addition, they require skilled operators. Their advantage is that they use surface water and their effluent is good quality drinking water, i.e. the same unit combines various pre - treatment and main treatment techniques.

2.6 WATER SUPPLY SCHEME

An example of how various treatment processes are linked in a water supply scheme is represented in fig 7.

Fig 7: Water treatment processes
Source: Davis & Lambert (97)



3.1 CLASSIFICATION OF ROUGHING FILTERS

Roughing filters are pre - filters that remove suspended solids by the passage of water through relatively coarse media.

The different roughing filter types are classified according to:

- location within the water supply scheme
- main application purpose
- flow direction
- filter design
- filter cleaning technique (Wegelin 1996).

Roughing filters can be operated either as horizontal flow filters (HFRF), upflow (UFRF), or downflow (DFRF).

In HFRF water flows in a horizontal direction through a gravel medium which decreases in size. The filter is usually divided in three or four sections which reduce in length. The gravel size may vary from a coarse 20 mm to a fine 5 mm (Wegelin 1996). The total filter length can be unlimited in theory, but in practice it is between 5 and 9 m. A layout of an HFRF can be seen in fig 8.

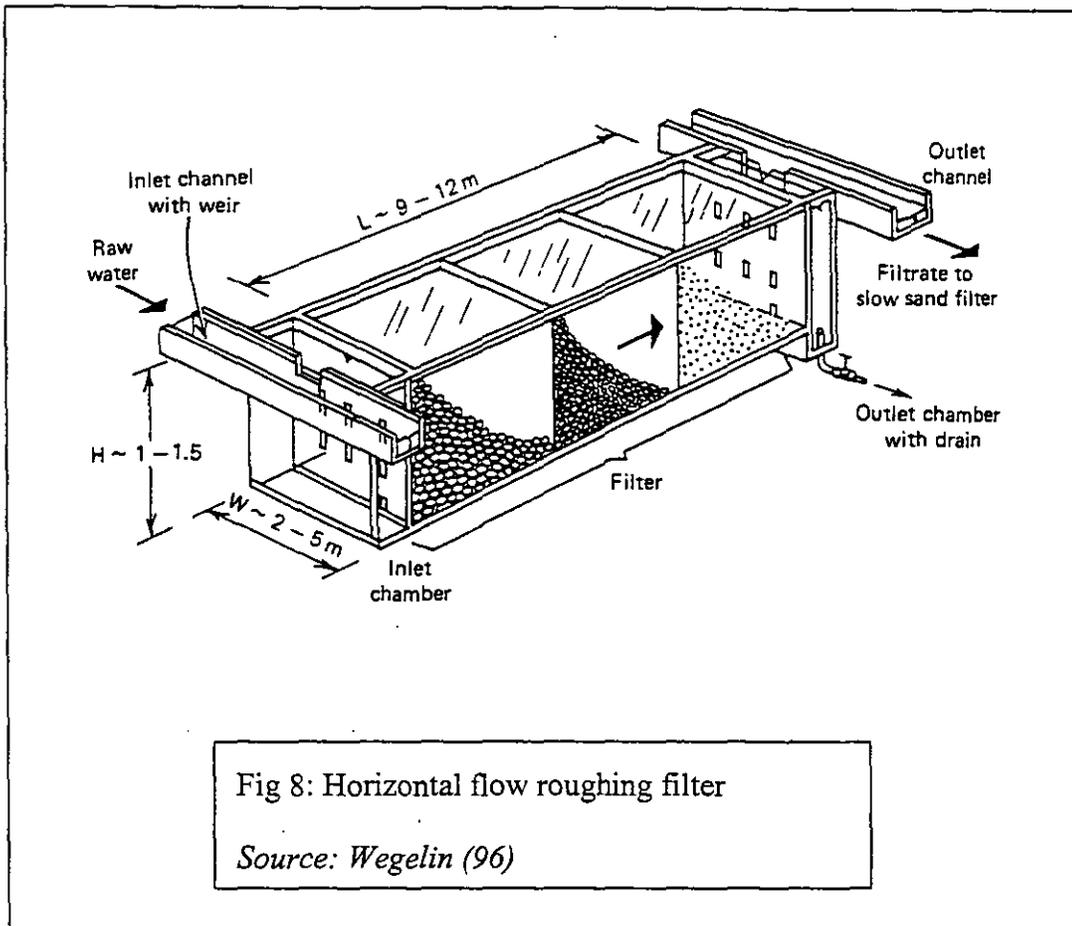


Fig 8: Horizontal flow roughing filter

Source: Wegelin (96)

In upflow roughing filters (UPRF), the water flows vertically upwards through a series of layers of graded material which are decreasing in size in the direction of the flow. There are two types of UFRF:

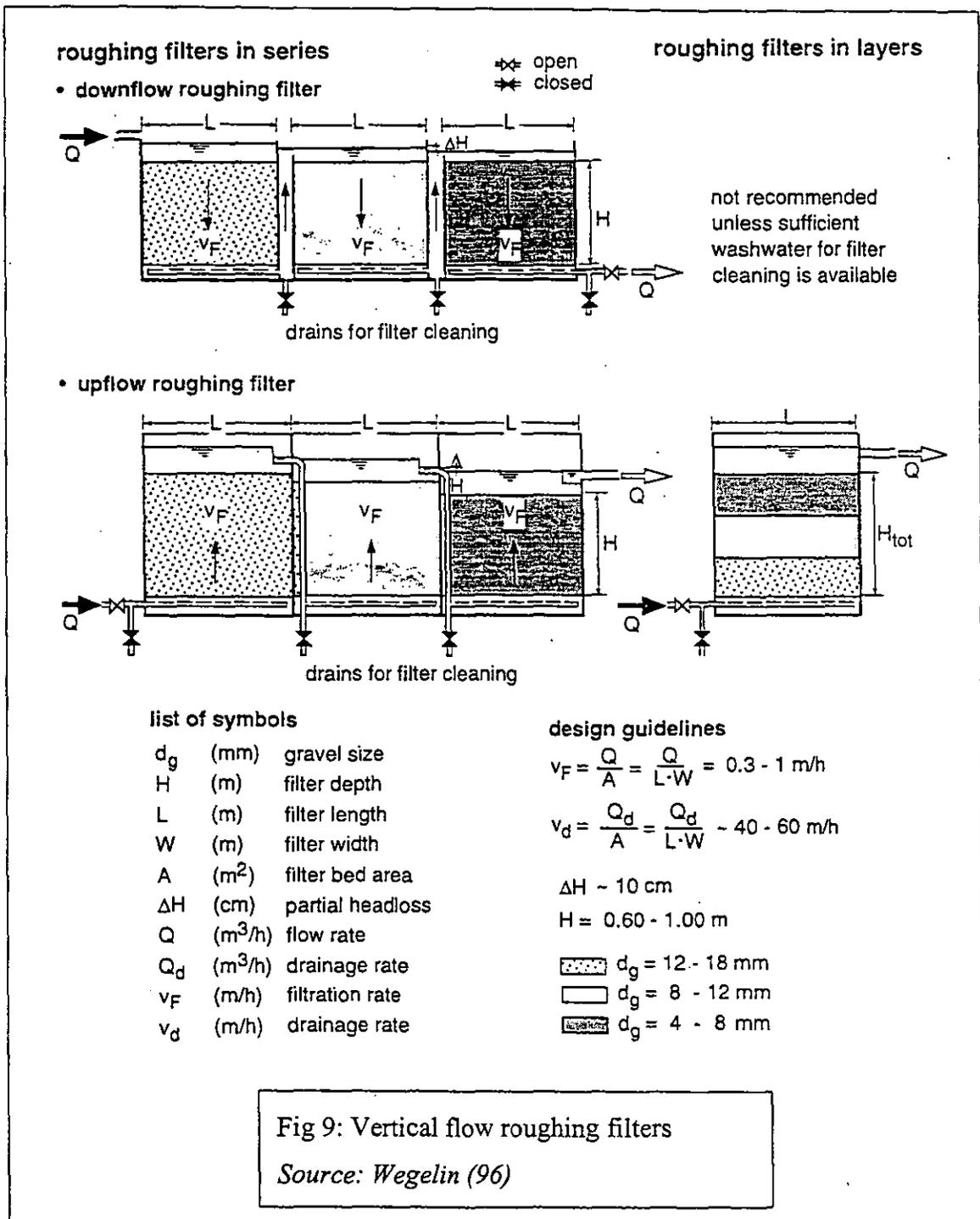
- UFRF in layers, where the layers of the filter material are contained in the same unit
- UFRF in series, where the layers of filter material are contained in two or more different units.

In downflow roughing filters (DFRF), the water flows downwards through a series of layers of graded material which are decreasing in size in the direction of the flow. Again as in the UFRF, there are two types of DFRF:

- DFRF in layers, where the layers of the filter material are contained in the same unit; in practice, this type of filters is not recommended for reasons that will be explained in 3.4.

- DFRF in series, where the layers of filter material are contained in two or more different units.

The layout of the various filters can be seen in fig 9.



In DFRF and UFRF, due to structural constraints the depth of the filter medium is usually 1 m if it operates in layers ; if the filter operates in series, assuming that there are three units, the total filter depth is 3 m.

Before presenting a more detailed design of roughing filters, one must understand how roughing filters work. Consequently, a brief description of the basic mechanisms of filtration is necessary.

3.2 FILTRATION THEORY

It is generally accepted that the capture of fine particles in suspension by filtration through a porous medium may be divided into three principal steps: transport, attachment and transformation.

i. Transportation mechanisms

In this process, the particles come into contact with the filter media. This contact can be achieved by various mechanisms such as:

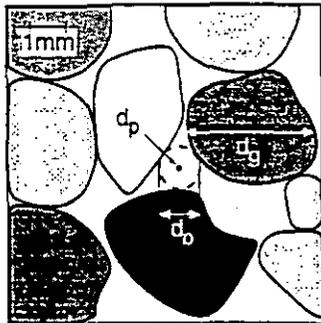
- Screening or Straining, where a particle in suspension flowing through a pore is larger than the pore opening. According to Ives (1975), screening is not strictly a transport mechanism. It has only limited importance in roughing filtration since the particles are a lot smaller than the pore sizes which correspond to the media usually used.
- Interception, where the particles whose centres are in streamlines near to the pore wall so that their radii cause them to touch the wall (Ives 1975). The particles which will adhere to the surface of the media will gradually decrease the pore size. As the particle size approaches the pore size, interception becomes straining. Again because of the relatively large size of media used in roughing filters, interception does not play an important role in the removal of impurities.
- Sedimentation, where the settleable solids are separated by gravity. The pores of the media can be described as miniature settling basins. According to Boller (1993), gravity dominates in this separation mechanism. It is the dominating factor for the transport of coarse grain diameters and particle sizes of $> 1\mu\text{m}$. According to Wolters et al. (1989), in upflow roughing filters, sedimentation can take place theoretically on

two places: directly on the granule surface perpendicular to the flow, or on a hydrodynamic shadow zone on the upperside of the granules.

- Hydrodynamic forces, where the particles are carried on flowlines which curve around the grains. According to Galvis et al. (1993), due to inertial and centrifugal forces particles may be forced to leave the flowlines and come into contact with the media grains. The removal efficiency increases with the increase of particle density and flow velocity and decreases with media size; this implies that the impact of this mechanism is limited in roughing filters because the filtration velocities are low and the media size relatively large.
- Diffusion, where very small particles exhibit a random movement due to their collision with water molecules (Brownian motion). The significance of Brownian motion, and the removal efficiency of diffusion, is confined to colloidal particles less than 1 micron (Boller 1993). For particles greater than about 1 micron, the viscous drag and inertia of the particle restrict the Brownian movement (Ives 1975); he also suggests that the importance of diffusion for the transport of colloidal particles increases with increasing temperatures.

The transportation mechanisms can be seen in fig 10.

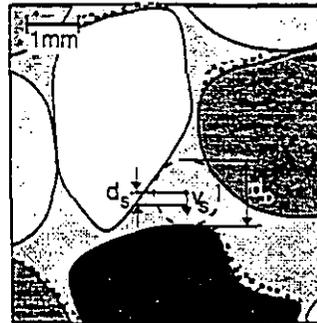
Screening



gravel size $d_g = 16\text{mm}$
 pore size $d_o = 2,5\text{mm}$
 particle size $d_p = 0,004\text{mm}$

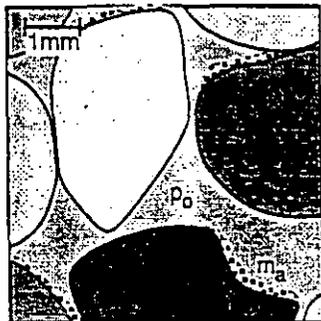
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Sedimentation



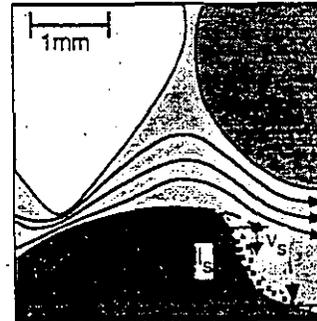
pore size $d_o = 2.5\text{ mm}$
 settling velocity $v_s = 0.01\text{mm/s}$
 settling distance $d_s = 0.1\text{ mm}$

SANDEC 25.8.95



porosity $p_o = 35\%$
 accumulated material $m_a = 2.5\%$

SANDEC 25.8.95



settling distance $l_s = 2\text{ mm}$
 settling velocity $v_s = 0.01\text{mm/s}$
 settling time $t_s = 200\text{ s}$

SANDEC 25.8.95

Interception

Hydrodynamic forces

Fig 10: Transportation mechanisms

Source: Wegelin (96)

ii. Attachment mechanisms

Once the particles are deposited on the media's surface, they are being held in place with a combination of mass attraction and electrostatic attraction. This combination is frequently referred to as adsorption (Galvis et al, 1993).

Van der Waals forces (or mass attraction) between particles decrease with increasing distance between these particles; the effects are limited for distances greater than $0.01\mu\text{m}$. Electrostatic attraction between opposite electrical charged particles (Coulomb force) is inversely proportional to the square of the distance between the particles. Due to double layer phenomena, the electrical charge of the grains may change constantly thus attracting particles with a positive or negative charge. These forces may supplement the transport mechanisms when particles are near media grains; this is referred to as active adsorption. According to Boller (1993) and Galvis (1993), the effects of active adsorption are limited in roughing filters.

Mass attraction and electrostatic attraction are more important though in roughing filters in holding the particles together to the grain surface once they have been in contact, which is also referred to as passive adsorption (Wegelin 1993, Galvis et al 1993).

According to Galvis et al (1993), another attachment mechanism may be attributed to the particles of organic origin which will be deposited on the media's surface and become the breeding ground of bacteria and micro-organisms. They will produce a sticky layer and may form large organic chains which may easily intercept smaller particles. According to Wolters et al (1989), in upflow roughing filtration the non inert organic material will accumulate and form chains predominantly on the hydrodynamic shadow zone on the top of the grains (Fig 11).

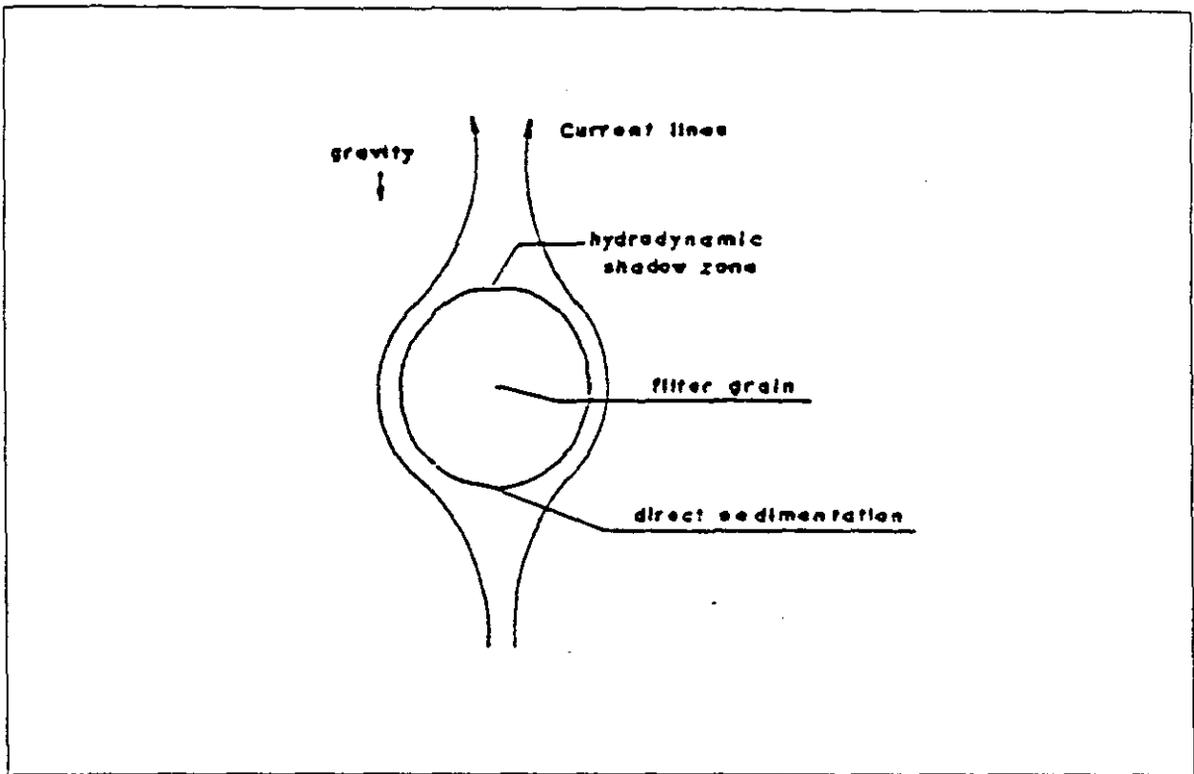


Fig 11: Hydrodynamic shadow zone for upflow filtration

Source: Galvis et al. (1993)

iii. Transformation mechanisms

There is increasing evidence that roughing filters are not only efficient in removing solid matter but also in improving significantly the chemical and microbiological water quality. Field experiences in rural areas of Peru show a significant faecal coliform reduction between 69.5 and 75%. Even though some of the reduction may be associated with the solids removal by physical mechanisms, the maturation of the roughing filter suggests the influence of biological phenomena. The examination of the microfauna colonising the mature gravel media were identical to those associated with slow sand filtration (Wolters et al. 1989).

Wolters et al (1989) also quote Quiroga who has reported a considerable reduction in colour and total iron content.

The two principal processes responsible for transformation are biochemical oxidation and microbiological activity (Wegelin 1996). Biochemical oxidation converts organic material into smaller aggregates and eventually into water, carbon dioxide and inorganic salts. It plays an important role in colour removal as well as in the precipitation and removal of iron and manganese.

Microbiological activity concerns bacteria that attach themselves to the surface of the grains. Some bacteria will oxidise part of the organic material and convert it to cell material for their growth. The condition in the filter is not conducive for some bacteria such as faecal coliforms, which will eventually die off when attached to the grains. This explains the reduction in total and faecal coliforms in roughing filters (Galvis et al. 1993).

The solid separation mechanisms (transportation, attachment and transformation) are represented schematically in fig 12.

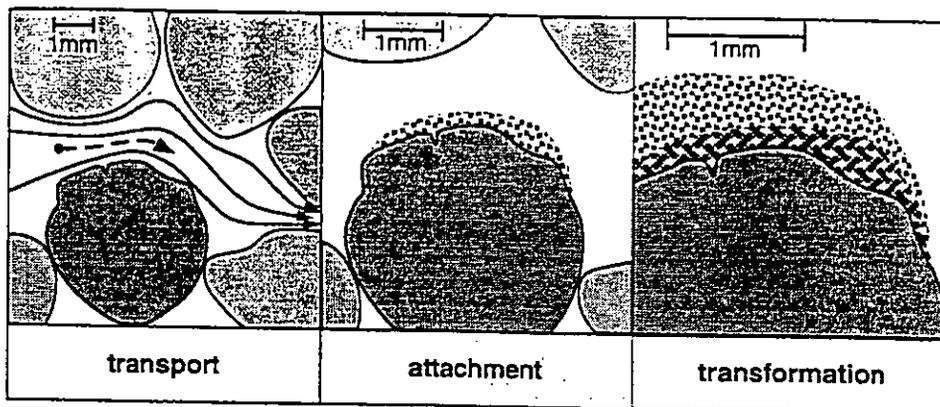


Fig 12: Solid separation mechanisms

Source: Wegelin (96)

3.3 ROUGHING FILTER DESIGN

The main elements of a roughing filter are the following:

- inlet flow control

The inlet flow rate must be controlled because the filtration rate must remain constant for efficient filter operation.

- raw water distribution

It should be homogeneous in order to achieve uniform flow conditions. The even distribution of the raw water can be achieved with the aid of submerged filter beds, inlet weirs covering the full filter width or perforated walls, depending on the choice of filter type.

- filter box

It must be watertight, of rectangular or cylindrical shape. It contains the filter media.

- treated water collection

The collection must be uniform; it can be achieved with a free water table on top of the filter bed (upflow filters), or a false filter bottom (downflow filters), or a perforated wall (horizontal flow filters)

- outlet flow control

It must prevent the filter bed from drying out; it can be achieved with the aid of a weir or a raised effluent pipe.

- drainage system

It is used for hydraulic filter cleaning. Perforated pipes or drains can be used.

Roughing filters have to meet the following three design targets Wegelin (1996):

- Reduce turbidity and suspended solids concentration to a level required for adequate slow sand filter operation.
- Produce a specific daily output
- Allow adequate operation during a determined filter running period.

Filter design has to meet these targets and is defined by the following design variables which can be selected within a certain range (Wegelin 1996):

- Filtration rate or filter velocity
- Average size of each filter medium
- Individual length of each specific filter medium
- Number of filter fractions
- Height and width of filter bed area.

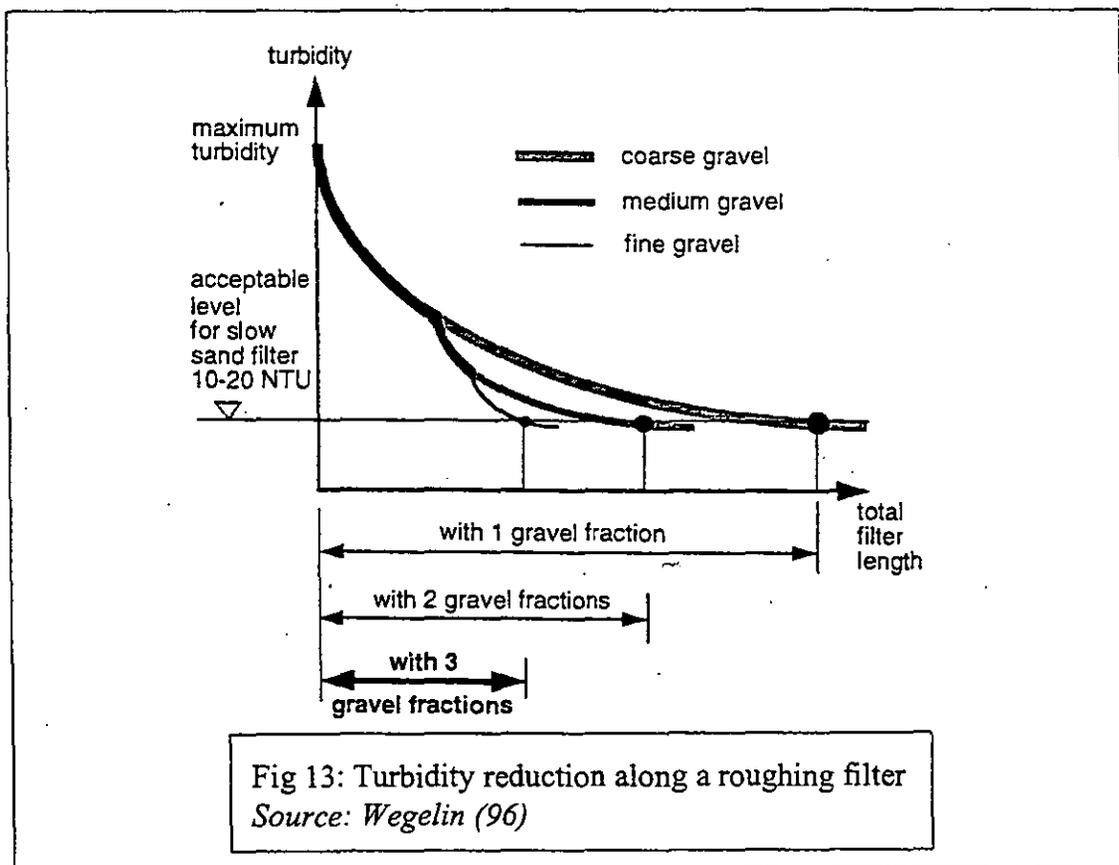
The filtration rates for roughing filters which are suggested in bibliography lie between 0.3 and 1 m/h. The values which are recommended in literature can vary quite a lot depending on the type of filter and the raw water characteristics. The filtration rate influences significantly filter performance although removal efficiency does not seem very much affected in between rates of 0.3 - 0.6 m/h (Galvis et al. 1993).

The most salient feature of roughing filters is the coarse filter grain which can not separate efficiently the colloids. In order to overcome this disadvantage, low filtration rates and relatively deep filter beds are necessary. Finer media may separate the solids more efficiently, but they also produce higher head losses which lead to limited run times. The design of succeeding layers with fractions from coarse to fine media is recommended, where the coarse media treat high inflow solids with low efficiency but low headloss and the fine media at the end treat the considerably lower solids loads and still keep headlosses acceptably low (Boller 1993).

Media size usually ranges between 4 and 25 mm. In theory, smaller filter media can improve filter efficiency. However, other criteria such as headloss, filter running time and cleaning must be taken into consideration. Media less than 4 mm may hinder hydraulic cleaning; media larger than 20 mm would require longer filter beds for an adequate removal. The uniformity coefficient, defined as the quotient between the largest and smallest size of filter fraction, should be in the order of 2 or less (Wegelin 1996).

The dimensions of the filter bed depend on the type of roughing filter. In vertical flow filters the depth is limited by structural constraints; the depth is usually between 0.8 and 1.2 m (Galvis et al. 1993). In HRF, the length could be in theory unlimited, but in practice it lies between 5 and 7 m.

The required overall length of a roughing filter can be substantially reduced with the use of differently graded filter fractions, as illustrated in fig 13. The number of filter fractions depends on the filter type; generally there are 3 fractions although in the case of URF up to 5 layers can be used (Galvis et al 1993).



The height and width are dependent on structural aspects. If the structures are not very shallow, there might be problems with water tightness due to the high hydrostatic pressure at the bottom of the filter. The bigger the total volume of the filter, the bigger diameter pipes must be used for inlet, outlet and hydraulic cleaning. The filter width should not exceed 4 - 5 m and the filter surface area should not exceed 25 - 30 m² and 4 - 6m² for vertical flow and horizontal flow roughing filters respectively.

Experimental results confirm the importance of filter length, gravel size and hydraulic loading rate as the principal roughing filter design variables. The relative importance of the individual design variables varied with the characteristics of the influent particulate matter. Mineral particulates similar to Kaolin clay were influenced in order of importance by filter length, media size and hydraulic loading rate. Organic particulates similar to *Scenedesmus* algae were influenced in order by hydraulic loading rate, media size, and filter length (Collins et al. 1994).

Galvis et al. (1993) suggest that filter efficiency is not much affected between rates of 0.3 and 0.6 m/h.

3.4 FILTER DRAINAGE

Roughing filters can be cleaned either manually or hydraulically. The former is a labour intensive and time consuming procedure which can prove to be problematic if frequent cleaning is necessary. In contrast, hydraulic cleaning is simple and efficient.

During the hydraulic filter cleaning, the water in the filter must be drained very fast (Wegelin 1996). The subsequent turbulent flow resuspends and transports the solids through the filter. Recommended drainage velocities vary between 10 and 90 m/h, depending on filter type and raw water quality. The importance of filter drainage for the regeneration of filter efficiency and hydraulic gradient are well documented in experimental lab work (Boller 1993, Wegelin et al. 1987) as well as field tests (Wolters et al. 1989)

Accumulations of large volumes of solids in the filter media decreases porosity, increases filter resistance and ultimately decreases filter efficiency. The accumulated

solids can become remobilized and get washed out in the effluent. After a critical point, the filter efficiency might even give negative values. It is therefore imperative to remove periodically the accumulated solids.

Hydraulic cleaning can be divided in the following transportation steps:

- a flush down the filter bottom
- a drag to the drainage system
- a wash out through the drainage system (Wegelin 1988)

The abrupt interruption and restart of the drainage process is called shock flushing. Some authors recommend shock flushing (Wolters et al 1989, Galvis et al 1993). According to Wolters (M.Sc. report), the fast closure of the drainage valves induces pressure waves in the filter bed which disintegrate the remaining deposits of settled material; once disintegrated, they can be flushed away by the subsequent drainage. Figures 14 and 15 (Wolters et al 1989), represent the effect of shock loading in an upflow roughing filter in Colombia. As it can be observed, there is an initial short turbidity peak in the drained water followed by a significant turbidity reduction and a small peak at the end of the drainage operation. Shock loading reveals new turbidity peaks for each drainage cycle. Similar observations were made in Peru and Switzerland (Wegelin 1989).

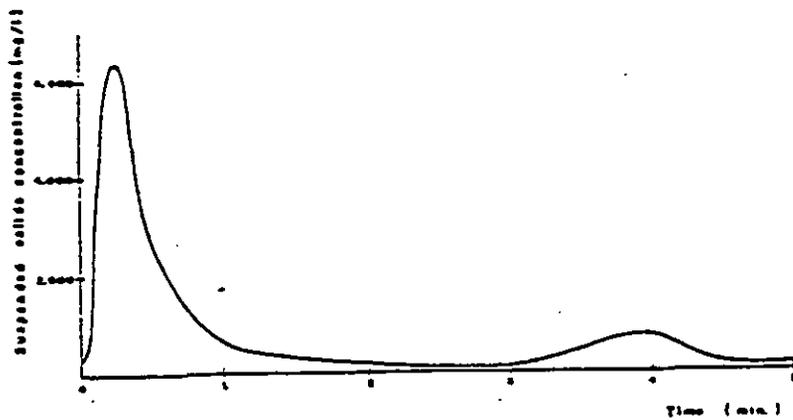


Fig 14: Suspended solids concentration during filter cleaning
 Source: Wolters et al. (89)

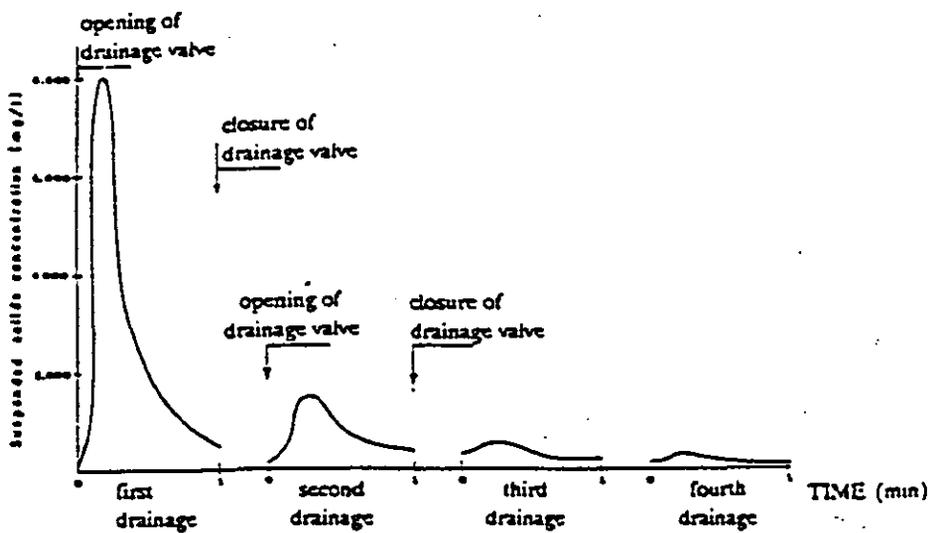


Fig 15: Effects of shock loading on drainage
 Source: Wolters et al. (89)

In contrast to the previous observations by Wolters, Wegelin (1989) does not recommend shock flushing as it can endanger the hydraulic installations and has little influence on the pressure changes in the filter bed.

In DFRF, during drainage all the deposited material would be carried to the bottom, where the finest filter media is located. This would lead to clogging of the filter bottom and would require a removal of all the filter material from the filter. Due to this reason, a DFRF in layers is not feasible (Galvis et al. 1993).

One useful feature to the design of UFRF is the use of a raised floor. Deposits that detach during normal operation (secondary deposition) are collected on the bottom of the filter. During the final stage of the drainage when the level of the water has dropped below the level of the floor, the turbulent flow conditions that still exist put the solids into suspension thus aiding their removal through the drains (Clarke et al. 1996).

3.5 COMPARISON OF VARIOUS TYPES OF ROUGHING FILTERS

The main advantage of a HFRF is its large silt storage capacity due to the deep penetration of the solids into the filter medium. Since the filter length of HFRF is greater than the total height of vertical flow roughing filters (between 5 and 9 m vs. maximum 3 m respectively), it is obvious that as far as silt storage is concerned HFRF have an advantage over vertical flow roughing filters (Wegelin et al. 1991).

In HFRF solids settle on top of the filter medium surface, accumulate as loose aggregates and drift towards the filter bottom as soon as they become unstable thus regenerating the filter efficiency at the top. HFRF are also less sensitive to filtration rate changes since resuspended solids drift towards the bottom or are retained by subsequent filter layers. Consequently, HFRF are less susceptible than UFRF and DFRF to solids breakthroughs caused by flow rate changes (Wegelin 1996).

UFRF has the advantage over DFRF and HFRF that the first solids separation takes place at the first layer of gravel at the bottom of the filter where the drainage system is situated, thus facilitating drainage of the deposited solids. As a result the hydraulic behaviour is improved, dead zones are avoided, the retention time is more homogeneous and the treatment process is overall improved (Galvis et al. 1993).

Land requirement gives an advantage to UFRF and DFRF since due to their design, they require less space for the construction when compared to HFRF.

One other difference between DFRF and UFRF is that during hydraulic cleaning, the bulk solids accumulated on top of the DFRF require a significant quantity of washwater; furthermore, the retained solids on top have to be flushed through the whole filter bed, thus soiling the relatively cleaner lower filter bed (Wegelin 1996). In UFRF, the washwater volume is equal to the volume of water in the filter box and since the majority of solids is retained at the bottom of the filter bed, they are easily carried away through the drainage (Galvis et al. 1993). Thus, the washwater volume is less in UFRF.

Sedimentation of solids in the direction of flow is privileged in the case of DFRF; theoretically DFRF should have a better performance than UFRF because the solids are more likely to settle on the media surface in the direction of the flow than under

concurrent conditions (Wegelin 1996). However, practical experience shows similar efficiency for both filters (Galvis et al. 1993, Wegelin 1996).

When comparing the various types of roughing filters for possible use in emergencies, the following observations can be made:

- Horizontal flow filters have a higher land requirement than vertical flow filters
- Upflow filters are significantly easier to maintain than horizontal flow and downflow filters, due to the ease and efficiency of the hydraulic drainage. In addition, the washwater volume for the upflow filters is less than that of the other types.

The type of roughing filter which would be best adapted to the design of a portable unit would be the upflow roughing filter due to their following advantages:

- their cleaning by drainage is very easy, thus it facilitates the operation and maintenance
- the washwater volume is low, so minimal water is wasted
- land requirement is minimum

As has already been mentioned, disinfection with chlorine is the most common method for providing safe drinking water. The low turbidity which is a prerequisite for an effective chlorination can be provided with roughing filtration or chemical coagulation.

When roughing filtration is compared to chemical coagulation and flocculation, it can be concluded that the former has the advantage of no chemical use and a relatively safe disposal of sludge when compared to the latter (Davies and Lambert 1997).

The disadvantage of roughing filters is the time it takes to construct and the use of gravel as filtering media. Gravel is unavailable in some locations and is difficult to transport long distances because of its weight. Consequently, in the first stages of an emergency it may be necessary to use coagulation with sedimentation until roughing filters are set up.

If polystyrene beads replace the gravel as filtering media, the logistical problems related to the use of gravel are solved. A portable filter using polystyrene beads can be easily transported and be functional within a short time.

The following section will present the research on roughing filtration using polystyrene beads as media carried out at WEDC.

3.6 POLYSTYRENE BEADS AS MEDIA FOR ROUGHING FILTERS

3.6.1 Introduction

Tests with filter material of different surface characteristics show a minor influence of the shape and the surface properties of the medium on the filter efficiency. The reason is that since gravity settlement is the most important removal mechanism, it does not matter on what type of surface the particles settle upon. In the relatively coarse media used in roughing filters, the macroshape of the pores (size and form) defines to a greater extent the filter performance than the microshape (roughness and surface porosity). In addition, the low filtration velocities of roughing filtration allow the particles to stay on the media surface simply by gravity forces (Wegelin 1989).

The filter material should have a large specific surface to enhance the sedimentation process taking place in the roughing filter, and provide high porosity in the filter bed to allow the accumulation of the separated solids. Generally speaking, any inert, clean and insoluble material meeting the above two criteria can be used as filter medium (Wegelin 1996).

Although gravel is the most common material, it was replaced with broken burnt bricks in field tests in Sudan, palm fibre in Indonesia and plastic material in laboratory test at the University of Newcastle in England. The results showed a similar turbidity reduction comparing gravel to burnt bricks and plastic material. The palm fibre notably showed a turbidity reduction of 67% when compared to the 39% using the gravel; the disadvantage was that it was not an inert material, consequently it caused odour and taste problems (Wegelin 1996 quoting Brown 1988).

Theoretically, polystyrene beads could be used as filtering media. This chapter will briefly describe the work that has been undertaken at WEDC trying to compare the removal efficiency of polystyrene beads to gravel. The author has not participated neither in the conception of the experimental method nor in the set up of the experiment; the author has collected some of the data and participated in their interpretation in conjunction with R. Reed.

3.6.2 Experimental method

The filter model chosen was the vertical upflow type using a single size aggregate. The vertical upflow type was chosen because it incorporated a simple self cleaning mechanism (hydraulic drainage) and occupies minimal floor space when compared to horizontal flow roughing filters.

Two identical filters were set up to run in parallel in the laboratory, one with polystyrene media and the other with gravel of similar size. The synthetic raw water turbidity was chosen to be within the indicative raw water quality limits for water treatment systems as given in the literature, i.e. 100 to 200 NTU (Galvis et al. 1993). The filters ran continuously for 40 days. The filtration rate was 0.75 m/h. Two 300 mm diameter PVC pipes were used to hold the media. The filter media depth was 1.0 m and the under drain was 0.5 m in depth. The polystyrene media was 'S' shaped with an average size of 22 x 14 x 12 mm; the stones were angular crushed granite of sieve size 25.4 to 9.6 mm. The set up of the filters can be seen in fig 16.

A second experiment was conducted using water from a nearby stream. This time both filters contained polystyrene media, but with different shapes and sizes: filter A contained a 0.05 m depth of 'S' shaped media (11 x 8 x 7 mm) and 0.75 m of smaller 'S' shaped media (6 x 4 x 3 mm); filter B contained 0.05 m depth of 'S' shaped media (11 x 8 x 7 mm) and a depth of 0.75 of polystyrene beads (average 3 - 4 mm). The rate of filtration was 0.75 m/h (Reed & Kapranis 1998).

A third experiment again used the stream for raw water supply. Both filters contained the same type of media, but with a different filter bed depth. Filter A contained 0.1 m of 'S' shaped media (11 x 8 x 7 mm) and 90 cm of polystyrene beads (4 mm); filter B contained 0.1 m of 'S' shaped media and 0.65 m polystyrene beads. The rate of filtration was 1 m/h (Reed & Kapranis 1998).

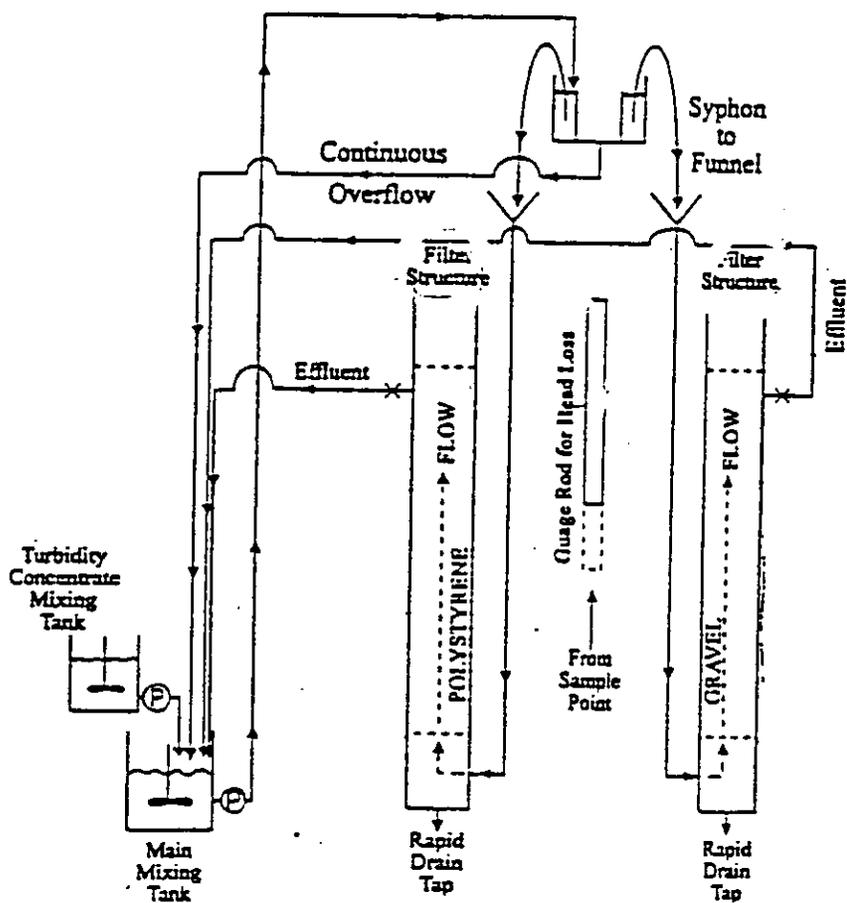


Fig 16: Set up of the experiment with polystyrene beads

Source: Reed & Kapranis (98)

3.6.3 Results

1st experiment

The results from the first experiment can be seen in fig 17 where polystyrene is compared to gravel for turbidity removal.

Both filters produced a series of results that showed an equivalent removal efficiency for both polystyrene and gravel for turbidity, with an average turbidity removal of 42% and 41% respectively.

Once the fact that polystyrene could replace successfully gravel for turbidity removal was established, the next step was to compare different types of polystyrene media which were commercially available.

2nd experiment

The results are presented in fig 18. As it can be seen, the removal efficiency for the polystyrene beads is overall slightly better than the 'S' shaped media. The average removal efficiency for the polystyrene beads is about 60 % and can exceed 90 % in some cases. It is interesting to note that the peaks in the removal percentage correspond to peaks in raw water turbidity; in other words, the more turbid the raw water, the better the filter works.

3d experiment

In the third series of testing, the effects of different filter media depths and a higher filtration rate were observed.

The results are presented in fig 19. Filter A had overall a slightly better removal rate, but the difference is not significant. It is suggested that the filter media depth between 1.0 and 0.75 m did not affect significantly the removal rate. The average removal rate for turbidity was 45%; again, due to the low turbidity of the raw water, the removal efficiency was low for turbidities < 10 NTU, but were greater than 60% for turbidities > 30 NTU.

Existing literature suggests similar removal efficiencies for various configurations of roughing filters using stones or gravel as media; Wegelin (80) produced results with

similar aggregates to the first series of testing giving removal efficiencies of 50 to 65 %. Upflow roughing filters in Colombia have resulted in the removal efficiency of 69 to 83 % for upflow roughing filters in series and 46 to 71 % for upflow roughing filters in layers (Galvis et al, 1993). The low removal rate of the first set of experiments was probably due to the large size of media used. The results of these experiments suggest that upflow roughing filters using polystyrene beads could produce similar results.

It must be noted that the only treatment parameter that was recorded was turbidity removal, ignoring faecal coliform reduction. The reason is that since the polystyrene beads are destined for use in a portable filter in emergencies, treated water will always be chlorinated before distribution; a presence of faecal coliformes in the effluent of the roughing filter would not be important, since the subsequent disinfection would eliminate the pathogens.

3.6.4 Conclusions from experimental work

The conclusions from the experimental work can be summarized in the following:

- Polystyrene beads are as efficient at removing turbidity from natural and artificial water as gravel of a similar size.
- The optimum removal efficiency for low turbidity water was observed using polystyrene beads of 4 mm diameter, a bed depth between 0.75 and 1.0 m and a filtration rate of 0.75 m/h. This may only be true however for waters of relatively low turbidities. Larger media may have to be used or filters in series if the turbidity is very high. A portable roughing filter can be built using this configuration.
- There is no significant difference on the removal efficiency between the two bed depths of 0.75 and 1.0 m.
- Turbidity removal rate varies with inlet turbidity. As inlet turbidity increases so does the removal rate.

Since polystyrene beads can replace gravel as filtering media, the next logical step would be to design a portable roughing filter that uses polystyrene beads as media. The following chapter will present the targets and requirements for the design of such a filter.

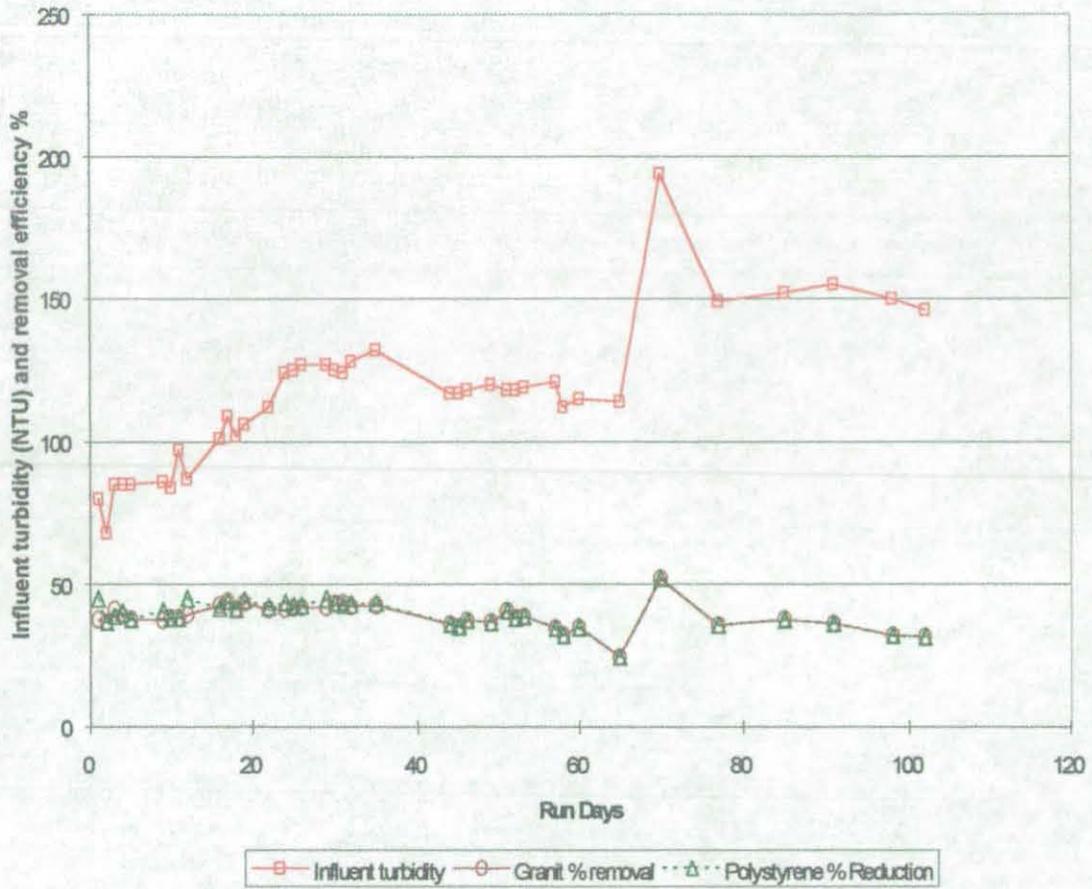


Fig 17 : 1st experiment
 Source : Reed 1997

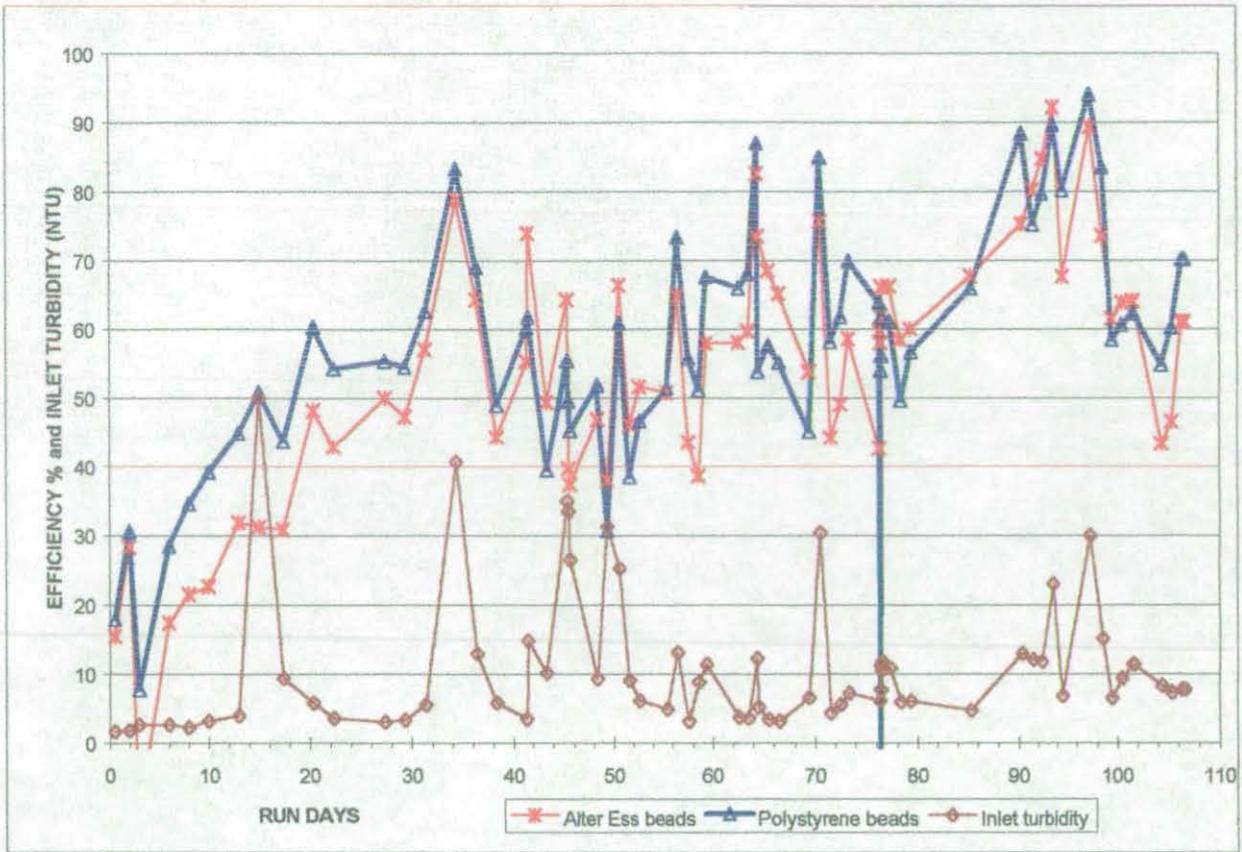


Fig 18: 2nd experiment
 Source: Reed 1997

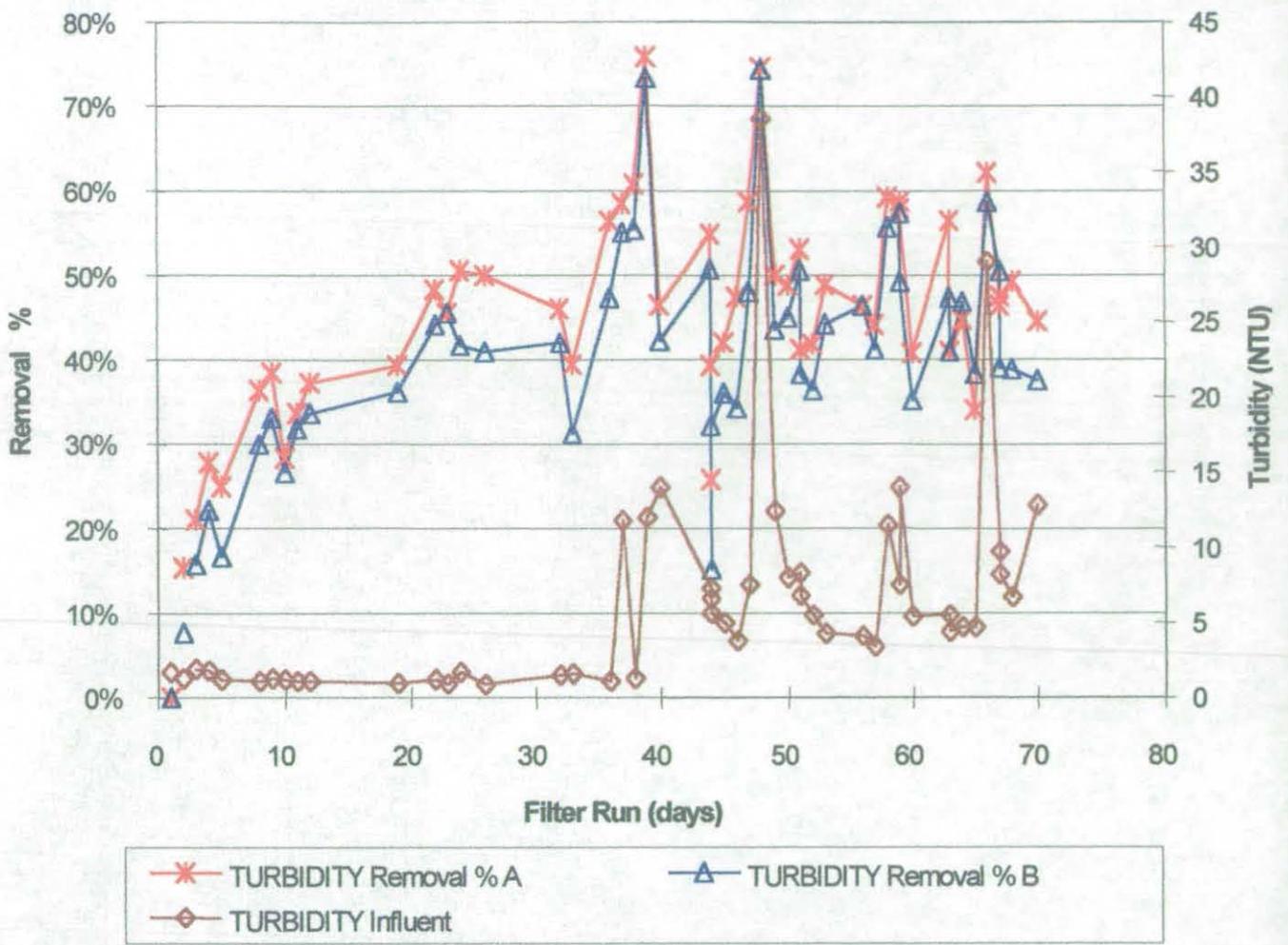


Fig 19 : 3^d experiment
 Source : Reed 1997

CHAPTER 4

CONCEPT DESIGN

4.1 DESIGN TARGETS

The filter has to meet the following design targets:

1. the daily output of low turbidity water (<10 NTU) must supply the needs of about 10,000 people in an emergency context (i.e. $10,000 \times 15 \text{ l} = 150,000 \text{ l/day}$)
2. it must be designed as a kit, i.e. it must be collapsible and fit into boxes ready for transport.
3. low weight and volume to facilitate transport
4. operate with polystyrene beads as media
5. rapid and simple installation on site
6. it must be simple to operate and maintain

The targets 1 - 6 are essential for the successful construction of the filter; they can be further developed as requirements crucial to the overall design.

4.2 REQUIREMENTS CRUCIAL TO THE OVERALL DESIGN

4.2.1 Daily output

The water demand depends on the stage of the emergency, the weather, socio-economic factors, etc. The quantity of water for survival level is 3 - 5 l/person/day (3 for cold weather, 5 for hot weather). The quantity for a longer term level is 15 - 20 l/person/day (House & Reed 1997).

It has been decided that the filter will be constructed within a 10 m^3 collapsible proprietary water tank with an effective cross sectional area of about 7 m^2 . The tank is ideal for the project, since it is collapsible with a butyl rubber liner and a

galvanised iron structure. The tank is used extensively by NGO's in emergencies. By using this tank, the water production will be enough for about (Annex 1)

- 8,500 people, assuming a per capita allocation of 15 litres per person per day
- 25,500 people, assuming a per capita allocation of 5 litres per person per day

4.2.2 Size of kit

The filter must be packaged as a kit; its dimensions must be similar to standardised boxes of water and sanitation equipment which are already being used by NGO's.

The standard 4 - wheel drive vehicle used by various organisations which work in emergencies is the Toyota pick up; such vehicles can access sites which cannot be reached with conventional vehicles and trucks.

A Toyota Hilux pick up can be used as an example. The dimensions of the cargo area are approximately 1.45 x 2.1 m (x about 1.5 m high

As a consequence of the above, the components of the various parts of the filter must be able to fit into one or more boxes with dimensions which will fit in the back of a pick - up.

4.2.3 Weight

It is obvious that the lighter the kit is, the easier and more economical it is to transport. Consequently, the choice of components and material must ensure that the weight is kept at a minimum.

In addition, it must be assumed that the kit will be manually loaded / unloaded without mechanical aids. If we assume that 6 people can carry a box and that one person can carry 50 kg, then the weight of an individual box must not exceed 300 kg. If the kit is divided into more than one box, then the weight of each box must not exceed 300 kg.

The usual max load for a Toyota pick up is 1000 kg; if the total weight of the kit is less than that, then it will be possible to transport it with one vehicle.

4.2.4 Use of polystyrene beads as filtering media

Perhaps the most important feature of the filter, and most certainly a novelty, is the use of polystyrene beads as filtering media. As has already been mentioned broken stones, gravel, broken bricks etc. are normally used as media. The novelty of using polystyrene beads is accompanied by some problems which can not be associated to the traditional media, such as their natural buoyancy when immersed in water.

4.2.5 Rapid and simple installation

Since the filter will be used in emergencies, it must be installed in the shortest time possible. The components of the filter must be designed in a way that they are simple and fast to erect.

Although arbitrary, it is assumed that the filter must be operational within 8 hours from the time of its arrival on the erection site, assuming that the site is already levelled.

4.2.6 Operation and maintenance

Operation and maintenance of the filter must be simple so that even unqualified personnel can supervise the operation and ensure that it is functioning properly. This implies that the procedure for the flow control and the drainage must be designed to be straightforward; in addition, it must be easy to verify when the filter requires drainage.

5.1 EMBODIMENT DESIGN

Embodiment design is that part of the design process from which, starting with the concept in the previous section, the design is developed in line with the technical criteria and in the light of new information. This section of the report will provide the detailed design and construction of the filter.

In order to facilitate the understanding of the flow of the development path, the report will follow the design of the various components in the same order as in the actual construction. These components are:

- structure of the actual filter (filter box)
- base
- drainage
- raised floor
- flow control
- treated water collection
- media

The components will be designed while taking into consideration the requirements presented in 4.2.

The detailed design of the components will be presented in the following chapter.

5.2 FILTER BOX

The filter box must be a watertight structure which will contain the submerged media. Since it will be part of the kit, its design must satisfy the conditions in 4.1.

Since the filter box will be part of a portable unit, the filter box itself must be designed to be portable.

Several types of portable water tanks were examined. The main problem with all the tanks was that they were designed to store water, not to become a part of a filter. The tank of choice should be strong enough to withstand the force from the polystyrene beads; in addition, it should be possible to make some alterations for the addition of the filter's various components such as the inlet, outlet, drainage, etc.

The search for a water tank to be used as a filter box was limited to two types of reservoirs: sectional tanks made out of GRP panels which can be bolted together and collapsible cylindrical tanks with a butyl rubber liner. The main disadvantage of the former over the latter was the price. Average prices were around £5500 and £2500 respectively

The collapsible type was selected because:

- They have been extensively used in emergencies by various organisations
- They are designed as kits for emergencies, i.e. they are lightweight as well as simple and fast to assemble

The tank which has been chosen for the filter box is a collapsible cylindrical tank with a 3.0 m internal diameter and 1.5 m height. The lining is made of high density butyl rubber and is held erect by a galvanised steel frame.

The term *collapsible* means that it is designed as a portable unit; the liner has the form of an open top cylinder, it is made out of butyl rubber pieces which are connected with ultrasonic welding; the frame is composed of various pieces of galvanised steel that can be bolted to each other. The tank by itself can be erected by two people in less than two hours.

The main advantage of this particular tank is that its components (galvanised steel and butyl rubber liner) are very strong. Similar tanks which are also used by NGOs use an aluminium frame for support which is not as strong as the galvanised steel.

Its main disadvantage is that the frame is eleven - sided; this fact created some problems in the design of the rest of the filter, notably the base and the lattice as it will be discussed in the rest of this chapter.

The tank was supplied with a 50 mm washout fitted with a ball valve. Although this washout did not serve any purpose to the design of the filter; it was not possible to remove it because the liner would have to be repaired.

5.3 SUPPORT BASE FOR FILTER

5.3.1 Introduction

Polystyrene beads are buoyant; when they are placed in the filter, they will float as soon as water enters the filter; it is obvious that for the filter to work, the beads must stay submerged. If some sort of mesh with a mesh opening smaller than the diameter of the beads is placed on top of the media bed, it will keep the beads from moving while allowing an unrestricted water flow. The next stage was to find a way to keep the mesh from moving upwards under the upthrust from the beads.

One possible solution that was examined was to put weights on top of the screen, heavy enough to withstand the upthrust from the beads; the beads are expected to produce an upthrust of approximately 28.8 kN - or 2834 kg (annex 2). It must be assumed that it could be impossible to find on site objects that weigh more than 2834 kg. If the objects had to be transported, then one might as well transport gravel and use it in the place of the beads.

Another possible solution that was examined was to fix the mesh to the water tank. It was originally thought to take advantage of the weight of the water in the tank in order to counterbalance the load from the beads. The mesh would be connected to a few uprights; the uprights would have a disc at the bottom which would be placed on the bottom of the tank; if the total load on the discs from the column of water above it was greater than the load from the beads, then the mesh would not lift. The disadvantage of this method was that the total area of the discs would be too large and would not fit in the tank.

The last option that was examined was to fix the screen to the tank's reinforcing frame; in that way, the upforce from the beads will be equally distributed over the 11 uprights of the frame.

The disadvantage with this idea would be that the water tank would be subject to forces that it was not designed for. Since the liner of the tank is not rigid, the force on the uprights would force them to lift and deform the liner; the force from the beads would be transmitted to the liner which is not designed to support such forces and it could be very well destroyed.

If the tank's frame was somehow fixed to the ground, then the frame would not lift and the liner would not carry any loads from the upthrust.

One must not forget that the filter must be a mobile unit, capable of rapid installation on any type of field. Under certain circumstances, it will be difficult, if not impossible, to fix the frame: for example, if the ground is too soft or not stable enough, one can not nail down the frame; one could "anchor" down the frame with some heavy stones, but these may not be readily available in certain regions; one could construct solid foundations out of reinforced concrete, but that would be complicated, expensive and time consuming.

The problem of the frame's fixing can be resolved with the construction of a rigid floor/base; the filter will stand on that base with its frame fixed on it. The upforce will thus be transmitted from the screen to the frame and then to the base.

It is obvious that since the base will be part of the mobile unit, it will have to satisfy the conditions of low weight, transportability and rapid installation; it must also be strong enough to resist to the media's upforce and the handling of unskilled persons. In addition, it must provide a solid support for the filter in non - uniform ground conditions.

5.3.2 Dimensions

Since the tank's floor is a circle with a diameter of approximately 3 m, the base will have to cover at least that area. The base will extend from that diameter by only a few centimetres, in order to save material and minimise weight.

5.3.3 Materials

The tank's reinforcing frame is composed of 11 vertical uprights, interconnected by 3 horizontal rods. Assuming that the load from the beads will be uniformly dispersed, each upright will have to carry approximately 4 kN (annex 3). The uprights must be fixed somehow to the base.

It was originally thought to use plastic palettes for the construction of the base. The disadvantage with the palettes was that they were designed to carry a load of an object placed on their surface. They were not designed to support a force pulling on their ends; consequently, they were simply not strong enough for the bead's load. This idea was abandoned.

The selected design for the base consists of an aluminium frame on which the tank's uprights are attached. The frame is enveloped by pieces of plywood and the total gives a solid floor which can be readily assembled.

The advantages of this base are numerous:

- low weight and high strength/weight ratio due to the choice of aluminium and plywood
- it provides a solid support for the filter
- relatively low cost, since the material is bought off the shelf
- easy to assemble
- easy to transport because it is readily dismantled

5.3.4 Components

The simplest design which will distribute uniformly the load from the upforce is the following:

Eleven aluminium hollow sections are placed on the radii of a circle with approximately 3000 mm in diameter; in the centre there is a metal disc with a diameter of 160mm on which the hollow sections are fixed. The tank's uprights are attached to the end of the sections. The plywood will 'sit' on the aluminium providing a base with a flat surface for the tank.

The uprights will be fixed on the hollow box sections with the aid of 'L' pieces made out of steel. The aluminium box section and the upright will be inserted and fixed on the 'L' pieces.

All the components of the base are discussed in more detail; they are:

- Aluminium frame
- Centre disc
- 'L' piece
- Floor

5.3.4.1 Aluminium frame

A layout of the frame can be seen in Drawing 1. As it can be seen, the hollow square sections divide the base into 11 equal parts. The first concern was to choose the dimensions and thickness of the aluminium pieces.

Round tubes were not considered, because at the point of contact between the tubes and the plywood, the load from the filter's weight would be distributed as a point load which could damage the plywood. A square or rectangular box section was thus deemed appropriate.

Since the uprights will be fixed to the aluminium frame of the base, the upforce from the beads will be transmitted to the latter. Thus a force of approximately 4 kN will be applied to the aluminium (annex 3).

Certain assumptions are made: we assume that since the tank is flexible, the sides will lift slightly due to the upforce. In addition, there will also be a small distance from the point where the upforce will be applied (connection between uprights and aluminium square section) to the point where the tank (when filled with water) will touch the floor with its full weight. The upforce will thus create a bending moment.

The calculations for the bending moment and the choice of aluminium grade and section can be seen in annex 3. Since it is impossible to estimate in advance the exact 'lifting' of the lining, we assume that the maximum distance between the point where the force is applied and the last point of contact with the lining is 300 mm.

According to the calculations of annex 3, a section with dimensions 75 x 75 x 3 mm could be safely used.

5.3.4.2 Centre disc

The centre disc will help to locate the position of the square sections.

The centre disc can be seen as part of the base in Picture 2 and in detail in Drawing 2.

The material of choice is aluminium for its high strength/weight ratio. Two identical discs are cut from a 13mm thick aluminium plate (the same thickness as the plywood), of a 380 mm diameter.

Eleven 12 mm holes are drilled on the disc, located on the perimeter of a 350 mm inner circle; 11 rods of equal diameter are inserted and glued into the holes. The aluminium sections can only rotate around the rods, on a plane parallel to the floor; they can not move in another direction since they are confined by the two layers of plywood and the two discs. That is one reason that they are not fixed on to the rods

but are allowed to rotate freely around them. The other reason is that this rotation allows for the aluminium to move slightly and fit perfectly on the frame's uprights, allowing for an automatic correction of uneven distances of the frame's components and/or construction imperfections.

One concern is the empty space between the edges of the aluminium sections and the discs; the disc's edges are close to the section's edges and the sections may buckle under the filter's weight. As a precaution, a piece of aluminium section is placed in the empty space between the gaps in order to distribute the load.

5.3.4.3 'L' piece

The 'L' piece can be seen in detail in Drawing 3. It provides the means to fix the frame's uprights to the square aluminium sections.

It is made out of two hollow steel square sections which are welded together; the cross sections are 40x40 mm and 70x70 mm, which correspond to the inner cross section of the hollow pegs and aluminium respectively.

Aluminium was the first choice for the material for the construction; the reason that it was not used was that there were no facilities available for aluminium welding.

The uprights and the aluminium sections slide over the 'L' piece. The uprights are fixed with two 8 mm stainless steel bolts; the aluminium box section is not bolted to the 'L' piece since the upforce can only move the 'L' piece on the vertical axis where the movement is restricted from the box section.

One important feature is that the 'L' piece and the aluminium square section must have a very close fit; if under pressure the edge of the 'L' piece is in contact with the aluminium box section, local buckling may occur on the aluminium.

Consequently, the L piece must be manufactured with a very close tolerance for the dimensions. The inside cross section of the uprights and the aluminium is 40.5 and 69.73x69.73 mm respectively. Commercially, the steel square hollow tubes are

sold as 40x40 mm and 70x70 mm. One problem is that these dimensions are not always accurate and depend on the manufacturer and each production batch.

As can be seen when comparing the dimensions of the steel and aluminium sections, the 70 mm steel section can not fit in the aluminium. Since the closest sections available commercially are 65 and 75 mm, it is necessary to machine the steel and reduce its cross section. The steel is thus machined in the workshop using a vertical milling machine. The resulting piece has an outside cross-section of 69.71x69.71 mm, which has an excellent fit with the aluminium box section. There is no need to machine the 40x40 mm steel section, since it also has a very close fit.

The design for the two bolts which connect the 'L' piece and the upright is presented in annex 4.

5.3.4.4 Floor

Plywood is the material of choice for the floor because of low cost, low weight and availability.

The plywood is cut into 11 similar pieces so that it can fit on the aluminium sections (Drawing 4). Its thickness is 13 mm, equal to the centre disc's thickness. The bottom layer of plywood is made out of different shapes, since it will simply be placed on the ground. As it can be seen from Drawing 5, the result is two flat surfaces which envelope the aluminium square sections. If the filter is erected on a flat, hard surface (i.e. a concrete floor) the bottom layer of plywood can be omitted.

Two types of plywood were tested; they are commercially called phenol-faced board and marine plywood. Both are weather resistant. There is not a significant difference in cost, but the marine plywood floor is about 24 kg lighter.

One concern is whether the plywood can withstand the full weight of the filter without structural failure. In order to distribute the load, two extra supports are used for each plywood piece; one supports the edge and the other is below the centre of gravity. The supports are cut off from a 'C' channel, with dimensions 75(channel) x 50 mm (leg).

The manufacturer has no information on the strength of the plywood. The best way to test the material is by testing, i.e. cut off the pieces, assemble the base and fill the tank with water. In order to compare the performance of the two types of material, 4 pieces of phenol faced and 7 pieces of marine type are used at the same time.

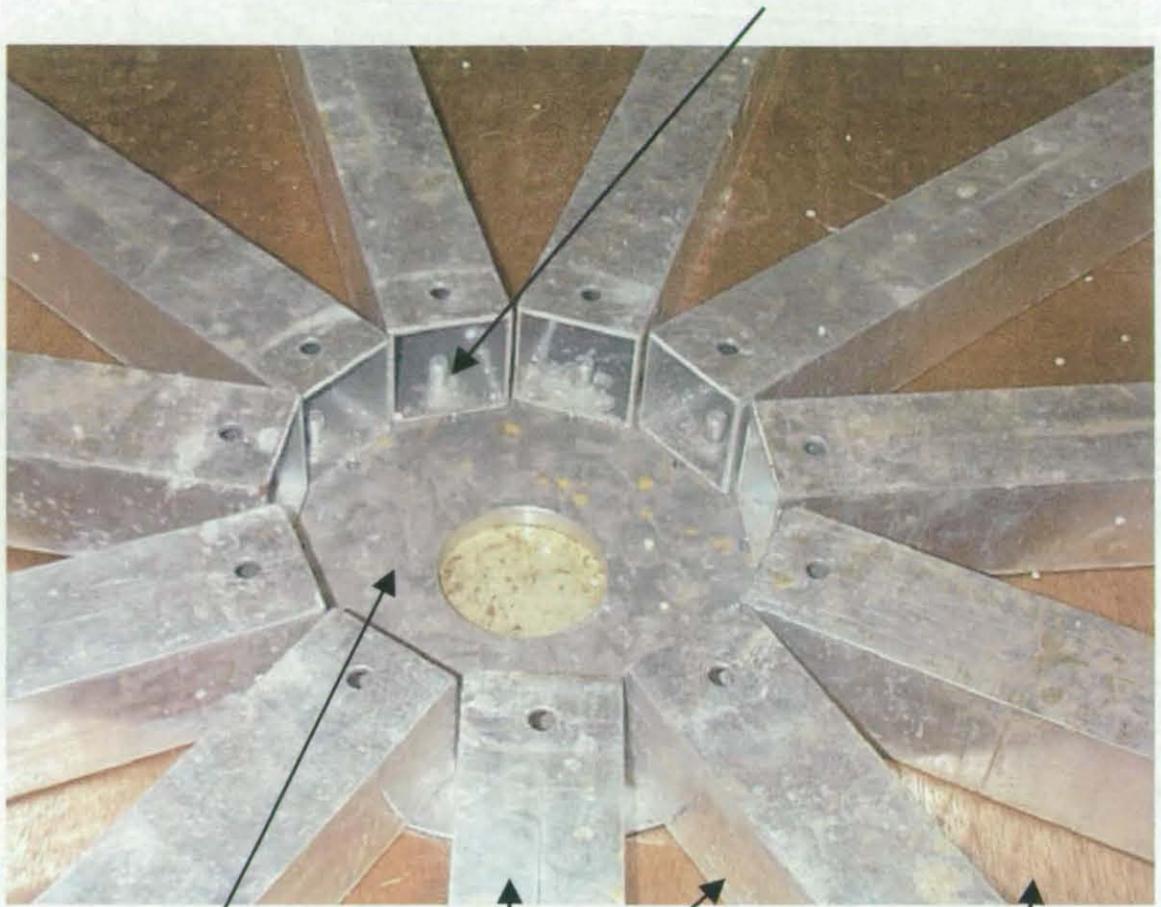
In order to test whether the support (aluminium C channel) of the plywood which is under the centre of gravity is necessary, the support was omitted from 4 pieces of plywood, two of each type.

The plywood comes in boards measuring 1220 x 2440mm. In order to have the minimum waste of material, 4 pieces can be cut from each board (drawing 6). As it can be seen, the disadvantage is that the pieces do not reach up to the centre disc; the remaining space is filled by an endekagon-shaped piece of plywood. This problem can be resolved by augmenting the centre disc's area to fill the space, i.e. to a disc of approximately 410 mm diameter.

The floor is illustrated in Pictures 2, 3, 4. The following details can be observed:

- the two different types of plywood (dark for phenol faced, light for marine)
- the top and bottom centre discs
- the eleven sided piece of plywood that fills the gap between the centre disc and the plywood floor elements
- the two different supports for the floor (the long and short pieces of aluminium channel)

Aluminium rod for locating
square sections



Aluminium disc

Aluminium square sections

Plywood

Picture 2 : Detail of bottom disc & aluminium square sections



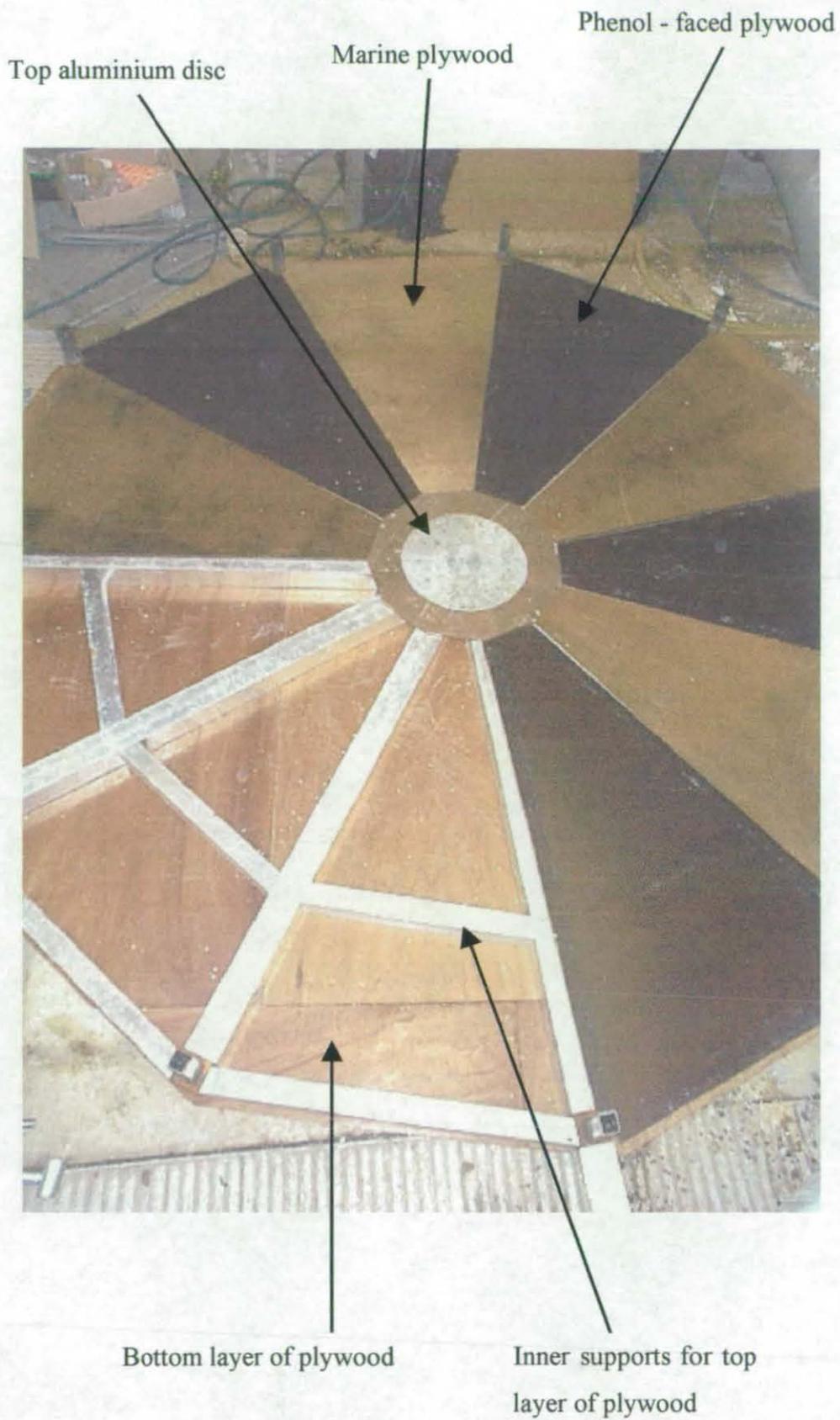
L Piece

Bottom layer of plywood

L Piece

Outer supports for top
layer of plywood

Picture 3: Aluminium frame and bottom layer of plywood



Picture 4: Base (aluminium frame, top & bottom layers of plywood)

5.4 DRAINAGE

5.4.1 Introduction

The drainage system has three basic objectives. It provides the uniform distribution of the water through the filter medium; it supports the filter medium; and it facilitates a uniform extraction of the wash water during the washing of the filter (Galvis et al. 1993).

Perforated pipes are used for the drainage. There are no specific guidelines for the design of drainage systems; some guidelines that can be found in the literature are a combination of theory and experimental work.

In the case of perforated pipes, the layout must provide for an equal distribution of flow to ensure the best possible hydraulic behaviour of the filter. Two principal systems exist: dividing-flow manifolds which are used to distribute a liquid in a filter medium and combining-flow to abstract a liquid from a filter medium. In the case of upflow filters, the manifolds can be designed to comply with both functions.

Galvis et al. 1993 have established a number of design criteria to facilitate the design of a drainage in roughing filters. The criteria are based on recommendations of Fair, Geyer and Okun (1968), studies by Hudson and colleagues (1979) and work by Galvis and Castilla in Colombia. Theoretical calculations support the criteria. According to the authors, systems designed on the basis of these criteria are already in operation and show good results. Table 1 contains a summary of design criteria for manifolds in roughing filters.

Table 2: Summary of design criteria for manifolds in roughing filters

Item	Combining-flow	Dividing-flow
R_o = $\frac{\text{surface area openings}}{\text{surface area gravel}}$	0.001 - 0.005	0.001 - 0.005
R_l = $\frac{\text{surface area openings}}{\text{surface area lateral}}$	0.3 - 0.5	0.4 - 1.0
R_p = $\frac{\text{surface area laterals}}{\text{surface area main}}$	0.3 - 0.5	0.4 - 1.0
Diameter of openings	6 - 19 mm	6 - 19 mm
Space between openings	0.1 - 0.3 m	0.1 - 0.3 m
Space between laterals	0.5 - 1.0 m	0.5 - 1.0 m
Flow in openings	4 - 5 m/s	4 - 5 m/s

Source: Galvis et al. (93)

5.4.2 Target values

The design of the pipes depends on the choice of the drainage rate and the filtration rate. As it has been mentioned, the design filtration rate is fixed at 0.75 m/h. It is more difficult to choose the drainage rate, since the values given in literature cover a wide range. For example, Galvis et al (1993) recommend a speed of 20 m/h; Wolters et al.(1989) have used a velocity of 4 - 6 m/h; Wegelin (1989) mentions that Wolters drained filters at Colombia at velocities ranging between 5 and 15 m/h and in Switzerland filters were drained at 20 m/h (initial) to 12 m/h (final).

Wegelin (1989) also mentions that experiments in Aesch, Switzerland, suggest that the relative mass of solids flushed out of the filter is almost proportional to the relative drainage rate applied to the filter (observations made for drainage rates ranging from 8 to 80 m/h, although it is not mentioned if the experiments apply to Horizontal or Upflow roughing filters). In other words, the higher the drainage rate,

the better the filter is being cleaned. It has to be mentioned though that the drainage rates applied to HRF's are higher than URF's due to construction limitations, i.e. the area of the floor is bigger in HRF's thus there is place for more drainage pipes and drainage valves.

The target drainage speed has been set at 20 m/h. This speed is about midway between the values suggested by literature.

5.4.3 Design of drainage pipes

Under normal operation, the flow velocity is low (0.75 m/h); the manifold design is not critical as the raised floor is expected to ensure the uniform flow distribution. Since the velocities are considerably higher (about 20 m/h) during drainage, this situation presents the main conditions for designing the manifold.

The drainage valves are fitted on the side of the tank; they must be as low as possible in order to have the maximum hydraulic head available. Due to the tank's iron frame, there is limited space for flanges to be fitted; a full face flange with a 75 mm opening is the biggest possible size. This means that there is a limitation for the diameter of the perforated pipes, i.e. they can not exceed 75 mm.

Next step is to decide how many of these valves and lateral pipes are needed in order to achieve the target drainage speed of 20 m/h. The procedure is described in annex 5. As it can be seen, the theoretical calculations suggest the use of three 87 mm pipes; due to the limitations mentioned in the previous paragraph, 75 mm pipes and valves will have to be used.

Even if the theoretical drainage speed will be less than expected, it was decided not to use more than three valves for the sake of simplicity and lower cost.

One other possible solution would be to connect the three laterals inside the tank to a main outside the tank, thus using only one valve. The disadvantage is that the diameter of the main would have to be about 213 mm, requiring a 200 mm valve (annex 5). The size of these components is considered to be very important for the needs of a mobile filter, so the option of three valves is retained.

The next step is to try to arrange the pipes in a way that will ensure a uniform water abstraction. Again, we are limited by the tank's geometry. The pipes must cover the whole area of the tank to provide an even distribution of flow. The arrangement of the pipes can be seen in Drawing 7.

For the inlet system, it would be possible to install separate pipework for the distribution of the raw water. In upflow filters, the drainage system can incorporate this function, thus simplifying the design. In order to achieve that, one of the washout valves can be connected to the inlet structure and during normal operation the pipes of the drainage system will act as a inlet manifold.

As it can be seen from drawing 7 the two pipes that are close to the tank's walls are connected. During normal operation, the water will enter from valve #1 and the flow will be distributed over the whole length of the pipes. Even if the pipe does not cover the whole area of the tank, it is assumed that the raw water will be distributed evenly due to the presence of the raised floor.

The drainage pipes in the filter can lift due to the weight of the ball valves and the flexible pipes which are connected to the washout; the ball valves are thus supported by a piece of plywood. The edges of the plywood are placed on aluminium square sections which are inserted to extensions of the L pieces.

Some design details worth mentioning are the following:

- UPVC pipes were selected because of their light weight, strength and ready availability; in addition, if maintenance is necessary they can be bought locally in many developing countries
- All the connections of the pipes with the flanges and fittings inside the tank are 'push fit', i.e. they are not glued so that the drainage system can break down to components long enough to fit in the kits' boxes
- The pipes are located to the flanges and fittings with the aid of a galvanised steel nail; a painted line on the pipes and fittings indicates the position of the nail. The advantage is that the correct positioning of the pipes is readily obtained; in addition, the pipes can not slide off the fittings

- If air is trapped in the pipes as the tank fills up, the pipes will become buoyant; this is avoided by drilling small holes on the top of the pipes through which air can escape
- The assembly of the drainage is facilitated by marking the tank's floor with lines which indicate the pipes' location; in addition, the pipes and various fittings are numbered in order to indicate the sequence of the various elements of the drainage
- The ends of the pipes are chamfered in order to facilitate the connection with the fittings.
- The valves are fitted with a quick release 75 mm fitting which can accommodate the type of flexible pipes typically used in the field by NGO's

5.5 RAISED FLOOR

5.5.1 Introduction

As it has already been mentioned in the chapter of literature review, Clarke et al. (1996), considered raised floors beneficial in the removal of deposits during normal operation as well as during drainage. A raised floor will thus be incorporated in the design. The floor will also serve as a support for the media.

5.5.2 Design of raised floor

Several conditions must be taken into account for the design of the floor:

- it must be collapsible for ease of transport
- the floor must have enough openings so that the water can flow freely
- it will be immersed thus it must be made out of a material which will not corrode

- structural strength is not important since the weight of the media is negligible; nevertheless, it must be strong enough to withstand the generated pressure during the filter drainage. In addition, it must support the weight of a person during the placement of the media
- in accordance to the overall design, weight must be kept as low as possible

The raised floor is 0.3 m above the filter's bottom. Clarke et al. (1996), also use the same height. The use of a galvanised steel mesh will satisfy the above conditions. The mesh of choice has a mesh opening of 50 mm with a wire thickness of 3 mm.

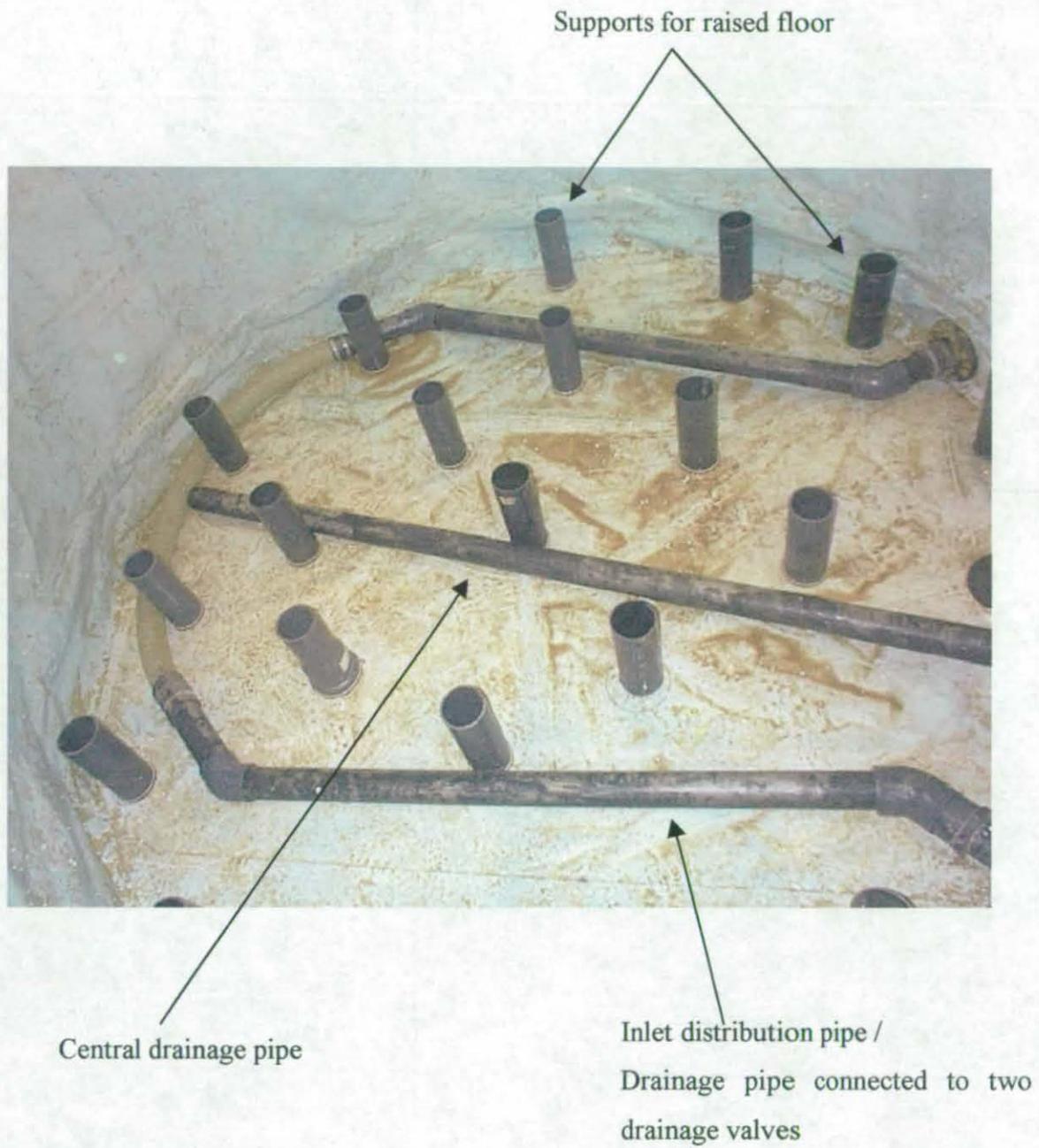
The mesh is not made as a single piece which will cover the tank, since it must be able to fit in the kit's boxes. It is made out of six pieces which are connected with rings and can fold into one piece with dimensions 1.10x1.5 m (drawing 8). A 25 mm plastic pipe is sliced open and fitted around the perimeter of the mesh to keep the sharp ends from damaging the tank's liner.

The supports which will keep the mesh at 0.3 m height are made out of 75 mm PVC pipes. The pipes are cut 0.3 m long. The bottom of the pipe is sealed with a circular piece of plastic in order to protect the liner from the edge of the pipe and distribute any load from the pipes to the liner.

While the tank was being filled with water, it was observed that the pipes were unstable because they were becoming buoyant. In order to overcome this problem a small hole (8 mm) is drilled near the bottom; as the water enters the tank, the pipes fill at the same time as the tank and prevents flotation.

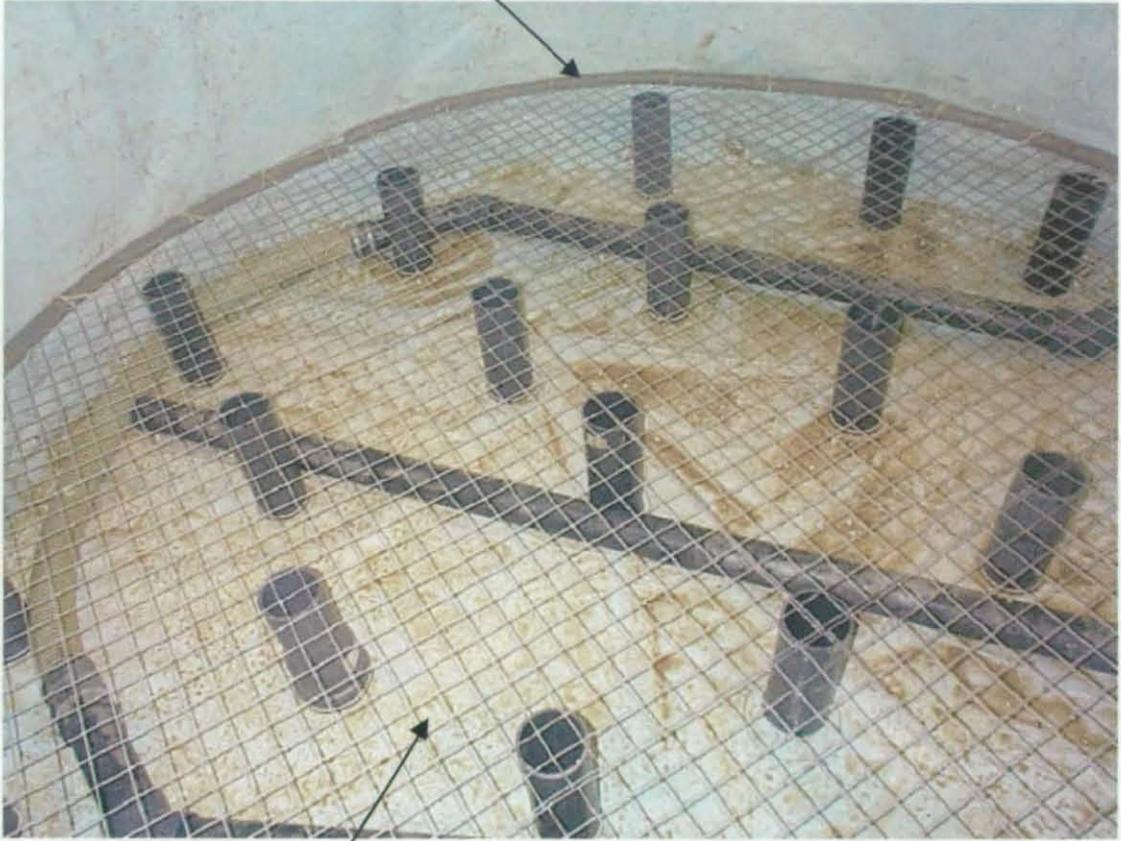
There are 29 support pieces. Their position is marked on the bottom of the tank in order to facilitate the floor's assembly. A person can walk on the floor by stepping on the supports.

The drainage and the supports can be seen in Picture 5; The drainage, the supports and the mesh can be seen in Picture 6. One of the drainage valves and the support from plywood can be seen in Picture 7.



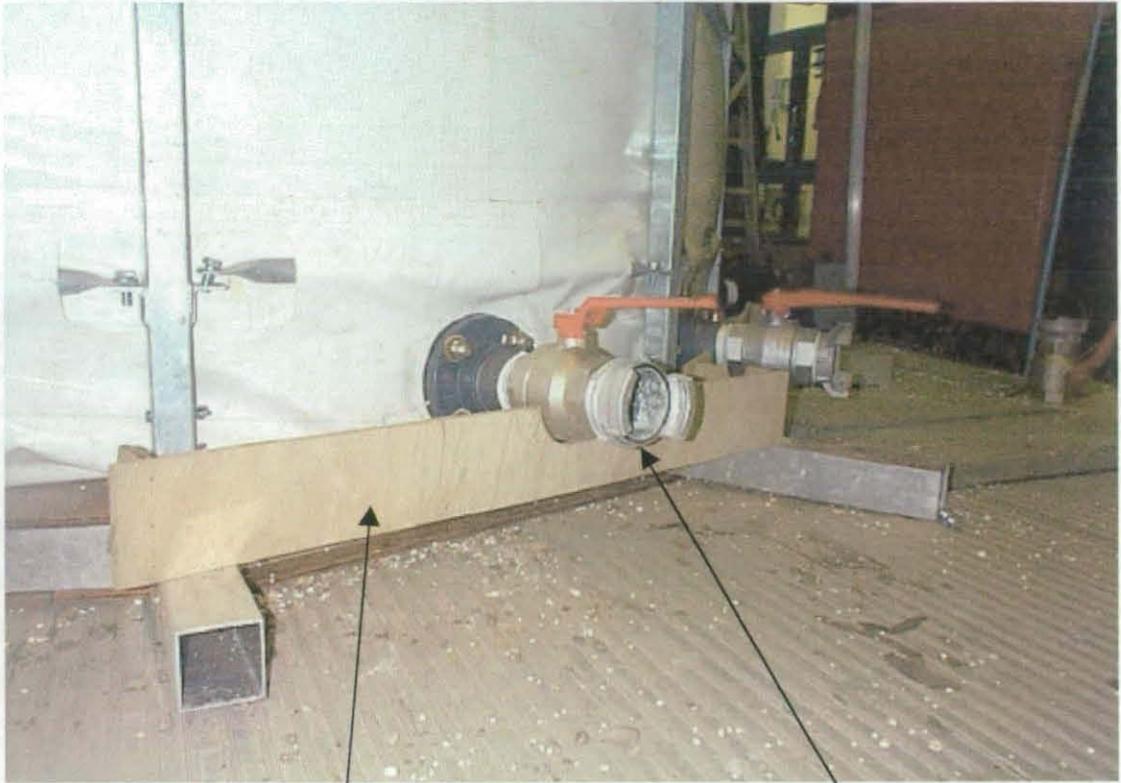
Picture 5: Drainage pipes and supports for raised floor

Sliced pipe for protecting the
tank's lining



Metal mesh

Picture 6: Raised floor



Plywood support for
drainage valve

75 mm drainage valve

Picture 7: Drainage valve with support

5.6 WATER COLLECTION

5.6.1 Introduction

In upflow roughing filtration, the water enters at the bottom of the filter, gets filtered through the media and is then collected at the top. Some designs in the literature propose a simple opening at the top of the filter, such as a flange, through which the treated water is channelled to the next stage.

Wolters et al. (1989), propose the use of a main and lateral drain system for uniform abstraction and collection of the treated water. They quote Castilla et al. (1985) in order to recommend some design parameters for the system. The design of the collecting system for this project is based on this recommendation.

5.6.2 Design

Although a system of laterals and a main ensures a uniform abstraction and collection, it presents the following disadvantages for a portable roughing filter:

- it can be difficult to fix a complicated system with many laterals and a large main on a collapsible tank
- the various pipes and fittings can have a significant weight

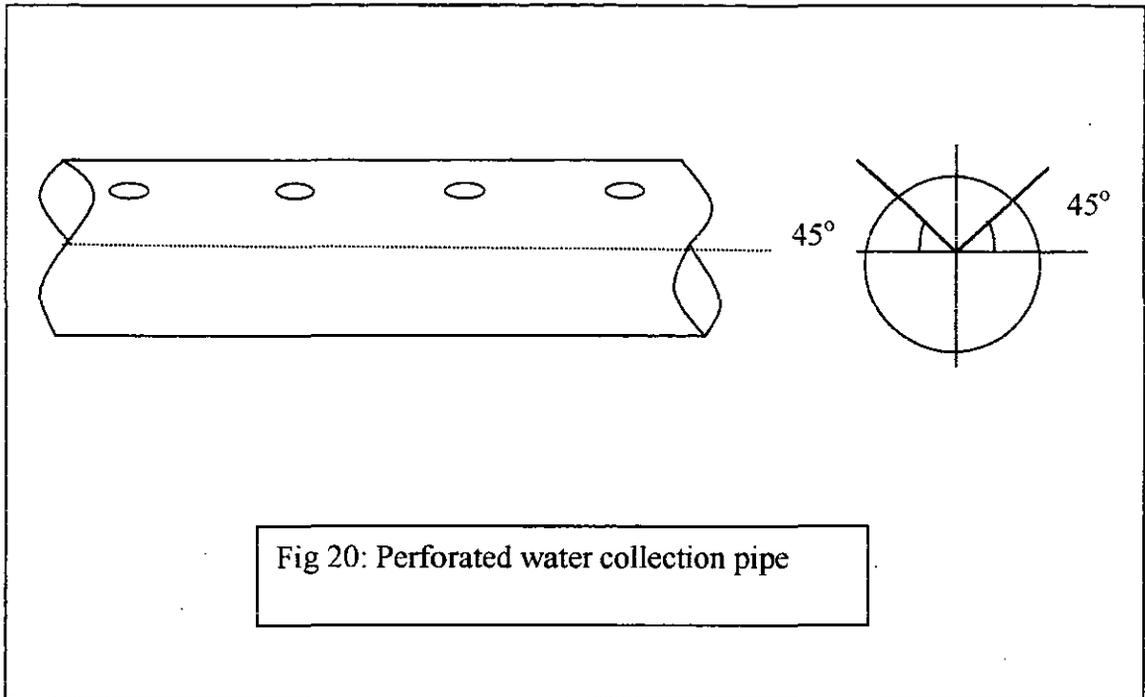
It was thus decided to simplify the system by using only one perforated pipe across the tank's diameter, connected to a 75 mm PVC flange. The possible disadvantage of a less than ideal abstraction and collection is overshadowed by the gain in weight and simplicity.

The pipe which is used is a 75 mm PVC pipe, the same as the ones used in the underdrain system. The orifices form an angle of 45° with the horizontal diameter of the pipe (fig 20). One end of the pipe is connected to the flange and the other one is sealed with a 75 mm rubber bung. The details are the following:

- * Diameter of openings (d_o): 12 mm
- * Number of openings (n): 20
- * Diameter of pipe (d_p): = 76 mm
- * Length of pipe: 2.58 m
- * Spacing between openings: 130 mm
- * Cross sectional area of the orifice (A_o): $\pi d_o^2/4 = 113.0 \text{ mm}^2$
- * Cross sectional area of the pipe (A_p): $\pi d_p^2/4 = 4534.1 \text{ mm}^2$
- * Flow velocity in the collection pipe : 0.32 m/s (Annex 6). The velocity is within the recommended values of 0.1 to 0.5 m/s (Wolters et al 1989).
- * The ratio between the total cross sectional area of the orifices and the area of the collecting pipe is:

$$A_o/A_p = 0.34$$

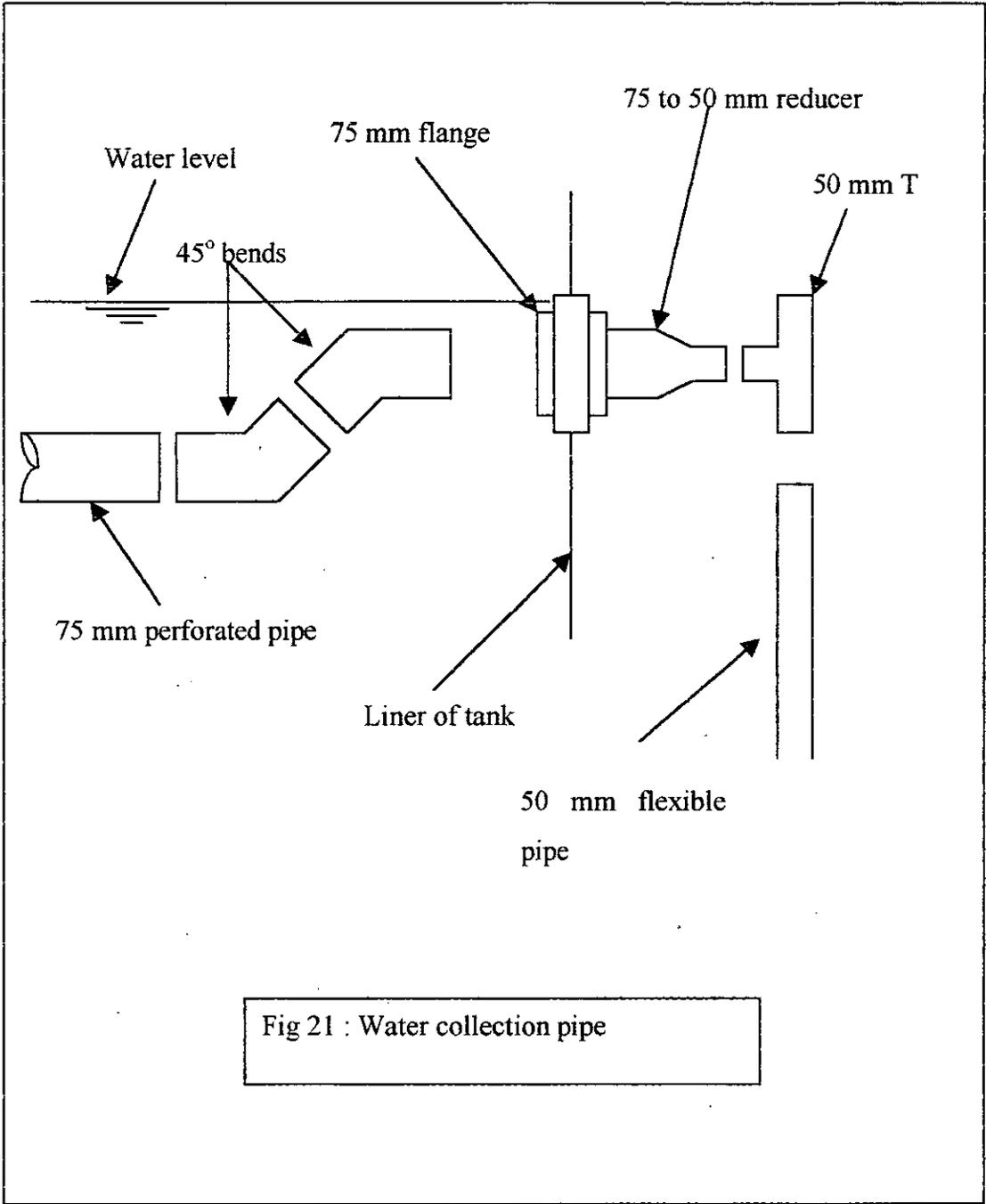
The above ratio is greater than the recommended value of 0.144 (Wolters et al. 1989). The reason is that literature recommends a system comprised of a main and some laterals, whereas in this particular filter only one lateral is being used.



5.6.3 Operation

The pipe is fixed at a few centimetres above the media. It has been observed during testing that if the pipe is not filled with water it becomes buoyant; as a result, the end which is not fixed is being raised. Since a part of the pipe is above the water level, water can not enter through the orifices which are above the water. In order to eliminate this problem, the pipe must be fully immersed; this can be achieved by placing the outlet above the pipe.

The above condition can be achieved by using two 75 mm 45° bends (fig 21). As can be observed, by connecting the two bends to each other and by placing them between the outlet and the pipe, the pipe is always immersed in the water.



As it can be seen from fig 20, the orifices are near the top of the pipe; when the raising level of water in the filter reaches the pipe, the pipe tends to float until the water starts entering through the orifices. By drilling two 10mm diameter holes on the bottom of the pipe, the water enters into the pipe and its weight keeps it from floating.

As it has been already mentioned, the pipe is placed above the media. Two galvanised steel pins hold in place the pipe to the two bends and the bends to the flange. The other end of the pipe is held into place with a metal hook which can be attached to the tank's frame.

The collected water leaves the filter through a 50 mm flexible pipe. A reducer fitting from 75 mm to 50 mm is connected to the 75 mm flange (external part) and a 50 mm T piece is connected to the reducer. The pipe is then connected to the T piece. The arrangement can be seen in fig 21.

As it can be seen from fig 21 the top opening of the T piece is not connected to anything; the reason is that if the 50 mm pipe at the outlet was connected directly to the flange, there could be an effect of siphoning if the other end of the pipe is submerged under water (i.e. connected to a tank, the inlet structure of a slow sand filter, etc.). A non - airtight cover on the top of the T piece is necessary to protect from possible airborne contamination; a piece of plastic mosquito screen is fitted around the top of the T piece.

One interesting phenomenon that was observed is that when the collected water leaves the filter and enters the T piece, the cascading water traps air and puts it in solution in the water in the 50 mm pipe. The presence of air creates a pressure difference between the top and the bottom of the pipe; as a result the water level rises in the pipe until it floods the T piece, and then it falls again since the air is out of the pipe.

The above phenomenon is repeated periodically. In order to eliminate the problem, a 5 mm rubber hose is inserted in the pipe (fig 22); the tube allows air in the pipe to replace the air lost in solution in the water. As a result, the air exits through the hose and the water stops rising.

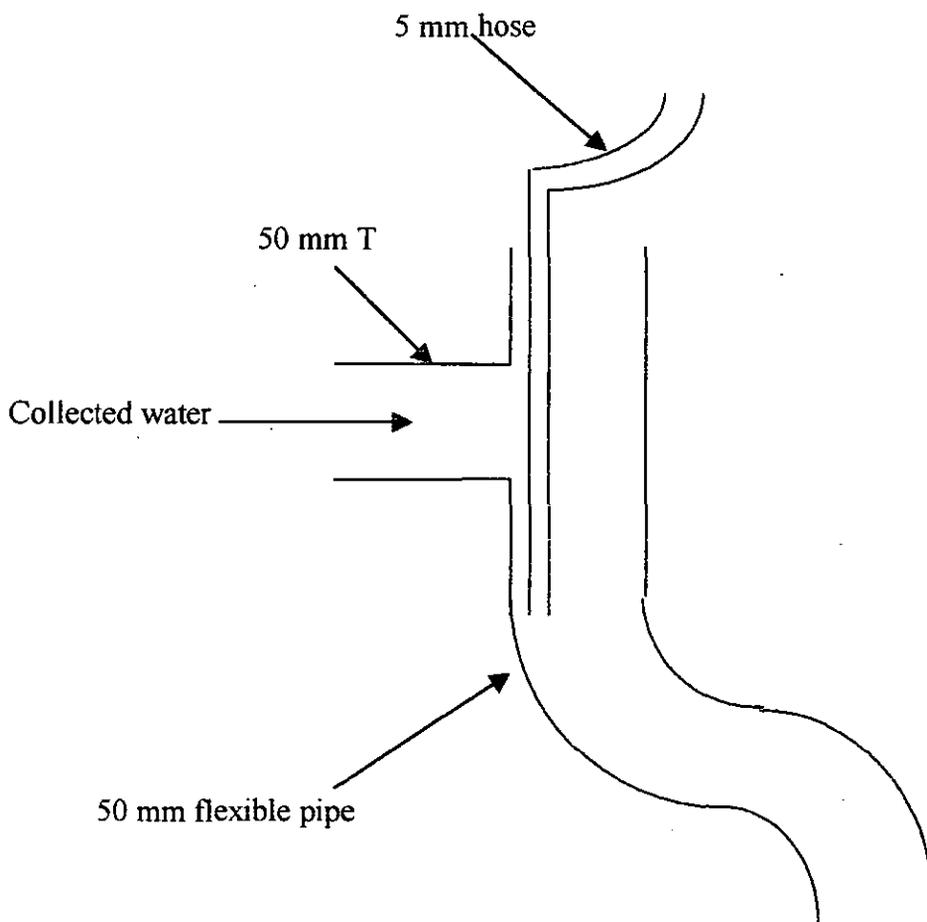
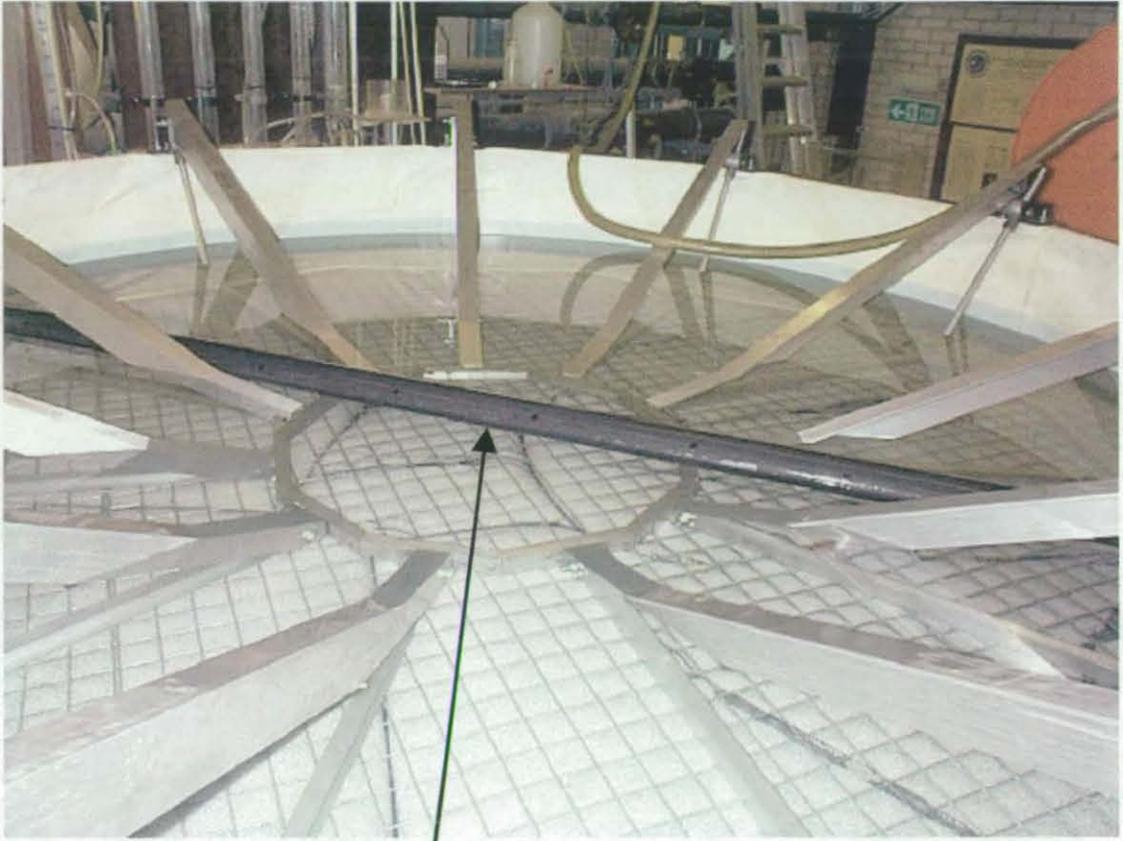


Fig 22: 5 mm hose in outlet



Water collection pipe

Picture 8: Water collection pipe

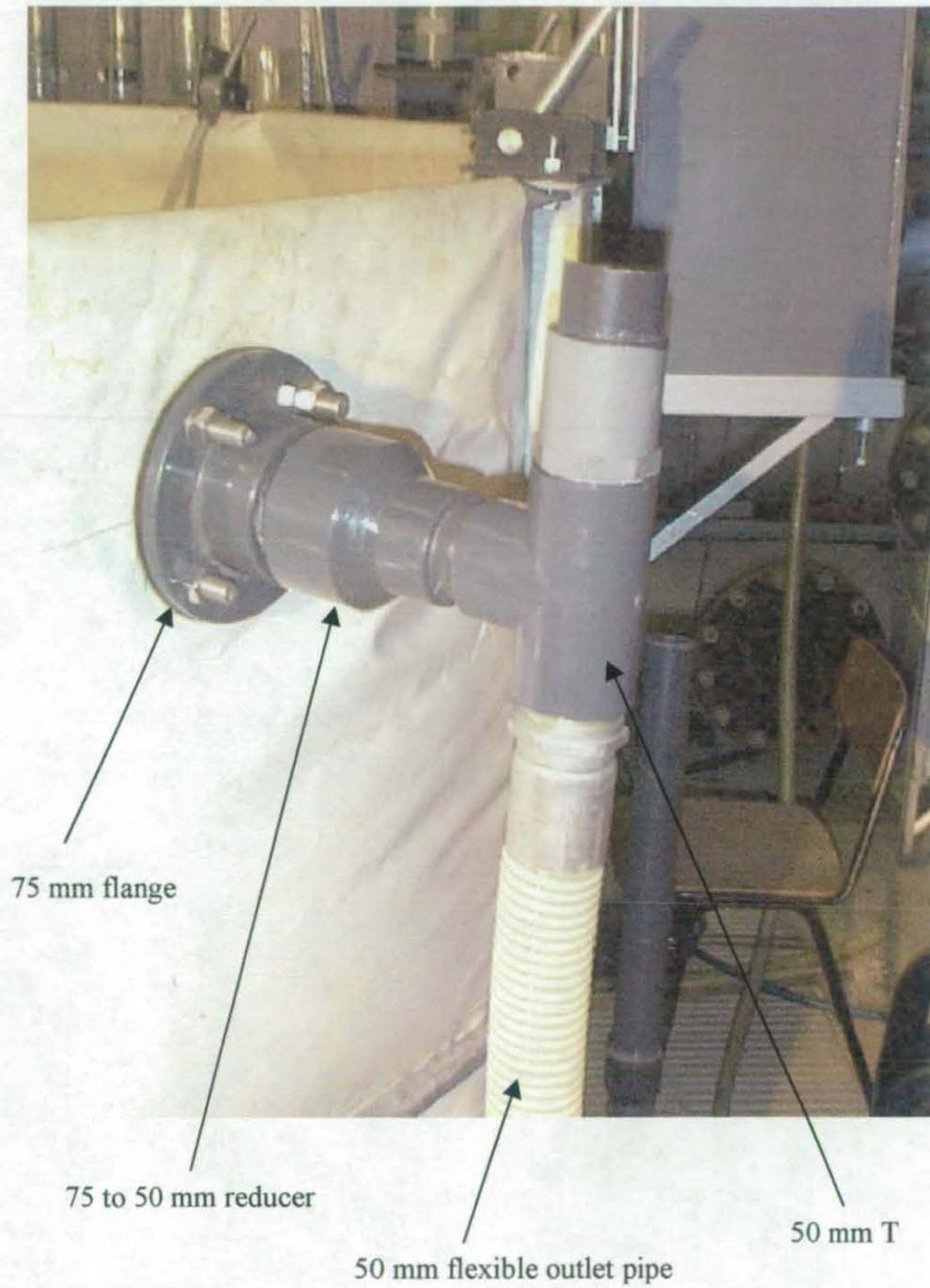


Water collection pipe

45° bends

75 mm flange

Picture 9: Detail of 45° bends at outlet



Picture 10: Detail of T piece at outlet

5.7 FLOW CONTROL

5.7.1 Introduction

The filtration rate is a very important parameter of the filter's performance. The solids removal can be influenced by its variation. As it has been discussed in introduction, the best results for the polystyrene beads are obtained at a vertical flow rate through the filter of 0.75 m/h. It is thus very important to ensure that this rate remains constant during the filter's normal operation.

The easiest way to control the flow is at the inlet. One flow measurement device is a V-notch weir.

Weirs are discharge measuring devices. They are formed from plastic or metal plate; the plate is set vertically and spans the full width of the channel; the weir itself is incorporated into the top of the plate. They are usually either rectangular or triangular, although other forms are available. A typical V - notch weir can be seen in fig 23. According to Chadwick & Morfett (1992) 'once the upstream water level exceeds the crest height, water will flow over the weir. As the depth of the water above the weir increases, the discharge over the weir increases correspondingly. Thus, if there is a known relationship between the height and the discharge, we need only to measure the height in order to deduce the discharge'. Triangular (V - notch) weirs are more accurate than rectangular weirs at low flows. Davies and Lambert (1997) also mention that 'up to 70 l/s the V - notch weir gives better overall accuracy than a rectangular weir'.

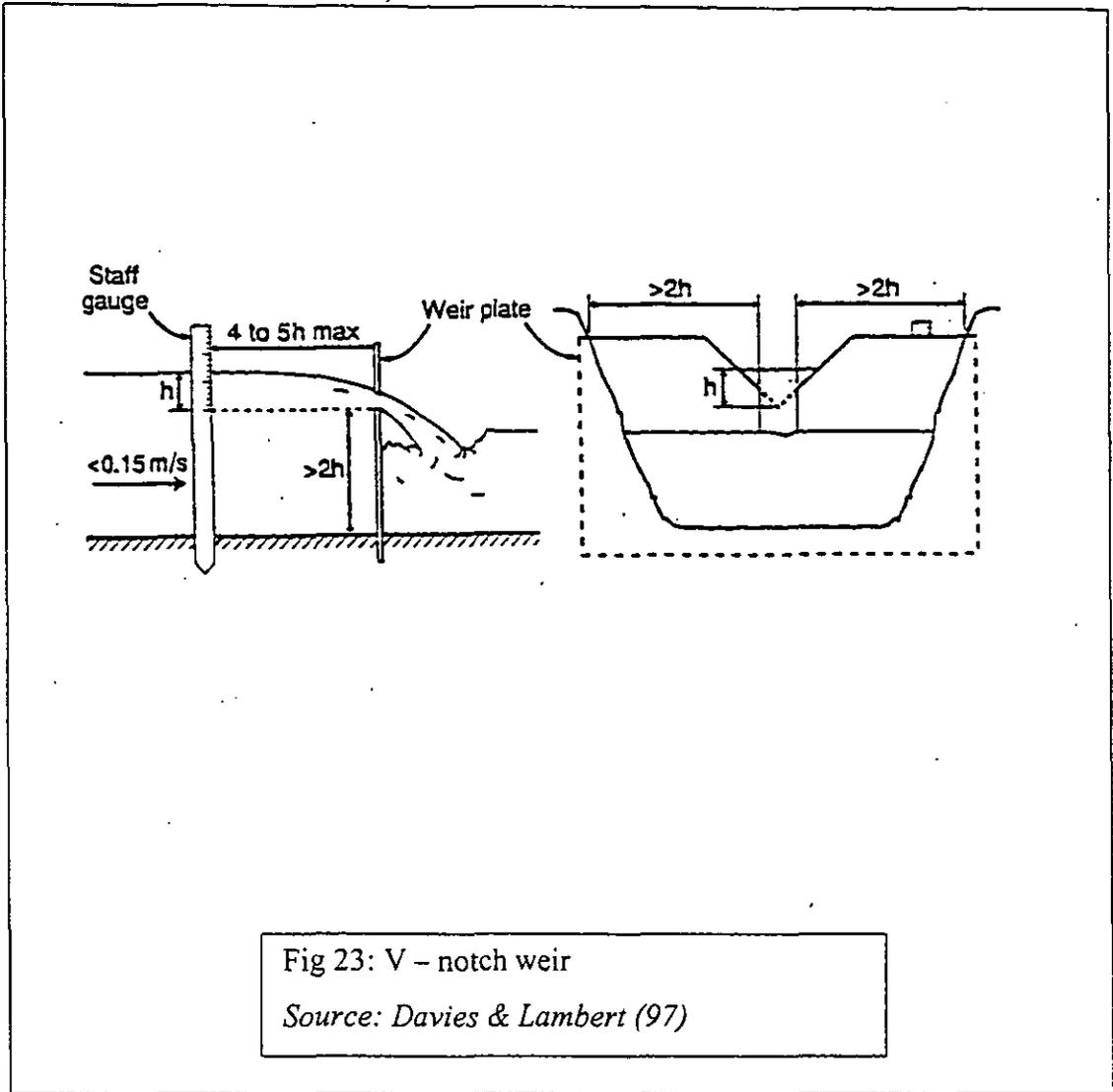


Fig 23: V - notch weir
 Source: Davies & Lambert (97)

5.7.2 Design Concept

The design considerations for the flow measurement device are the following:

- it must be reasonably accurate
- it must be lightweight, and
- it must be simple to operate so that even unqualified personnel will be able to ensure the filter's operation

A flow control box that contains a V - notch weir satisfies the above conditions.

As can be seen from drawings 10 & 11, the box is divided by a V - notch weir into two compartments. The first compartment contains the incoming raw water. A 25 mm diaphragm valve which is connected to the raw water source regulates the flow. The water's level can be measured with the aid of a graduated piezometer which is located on the side of the box; the water level which corresponds to the target flow can be marked on the piezometer tube. A baffle is installed to reduce the turbulence from the incoming water.

The second compartment contains the water that overflows the weir. An opening at the bottom is connected to a 50 mm pipe. The box is fixed at such a height on the side of the filter that the 50 mm opening is always below the level of the water in the filter during normal operation; the consequence is that the pipe will always be full of water thus avoiding air being drawn into the filter.

One important feature of the flow control box is that headloss variation in the filter can be recorded by the water level in the second compartment. As the filter resistance increases with operation, the level of the water in the compartment will rise. It is thus possible to determine in advance the acceptable headloss and mark the level of the water which corresponds to it. When the water reaches that mark in the box, then the operator will be expected to drain the filter.

Another important feature is the simplicity of the flow measurement; the operator only needs to manipulate the diaphragm valve so that the water in the first compartment reaches the mark on the piezometer which corresponds to the desired flow.

Thanks to the aforementioned features, it is thus possible for people who can not necessarily make calculations or read and write to operate the filter. All they would have to do is open the diaphragm valve until the water reaches the pre-marked level on the piezometer and open the drainage valves once the water reaches the pre-marked level in the second compartment.

5.7.3 Dimensions of the flow measuring box

The design of a V - notch weir is well documented. A typical example from the book of Davies and Lambert (97) was seen in fig 23. The recommended dimensions are related to the expected height (h) of water above the weir's crest. As it can be seen from the figure, (h) should be measured at a distance between 4h and 5h upstream; this is in accordance with BS 3680. The reason is to avoid the effect of drawdown at the crest. The crest must also be well above the bottom of the plate ($> 2h$), so that the water overflows freely.

According to the calculations in annex 7, the expected height of the water is about 80 mm. According to the recommendations based on the theoretical design, the dimensions of the box should be as follows:

- distance of measuring gauge from weir: between 4h and 5h \Rightarrow between 4 x 80 and 5 x 80mm \Rightarrow between 320 and 400 mm
- height of crest above the bottom of the plate: $> 2h = 2 \times 80 \text{ mm} = 160 \text{ mm}$
- width of weir plate: $> 2h$ on each side of the V - notch plus the width of the notch when the height of the water is 80 mm $\Rightarrow \{(2h) \times 2\} + 90 \text{ mm} = 410 \text{ mm}$.

The box was originally fabricated with the following dimensions:

- First compartment: 500 mm long x 400 mm wide x 500 mm deep
- Second compartment: 200 mm long x 400 mm wide x 500 mm deep.
- Location of measuring gauge : 300 mm from the weir.

When the weir was tested with the target discharge of 1.47 l/h, the results were quite satisfactory; the surface of the water in the first compartment was relatively undisturbed and the level of water in the piezometer was stable thus giving an accurate measurement. The disadvantage was that the box was heavy and bulky when filled with water and thus difficult to fix to the tank; in addition, it would take too much space in the kit.

It was thus decided to reduce the dimensions, making a compromise between the accuracy of measurement and the volume and weight of the box. Consequently the dimensions of the box are smaller than that recommended in literature. First, the distance of the measuring gauge from the weir is at 97 mm, much less than the recommended 320 - 400 mm. Second, the width of the weir plate is 250 mm, less than the recommended 410 mm.

The filter box is made out of a PVC sheet, 6mm thick. The plastic is opaque and the box is covered in order to prevent algal growth. The various pieces are assembled with hot - air welding. The V - notch weir has a 60° angle. For that angle, the height of water that corresponds to the target flow is about 80 mm (Annex 7).

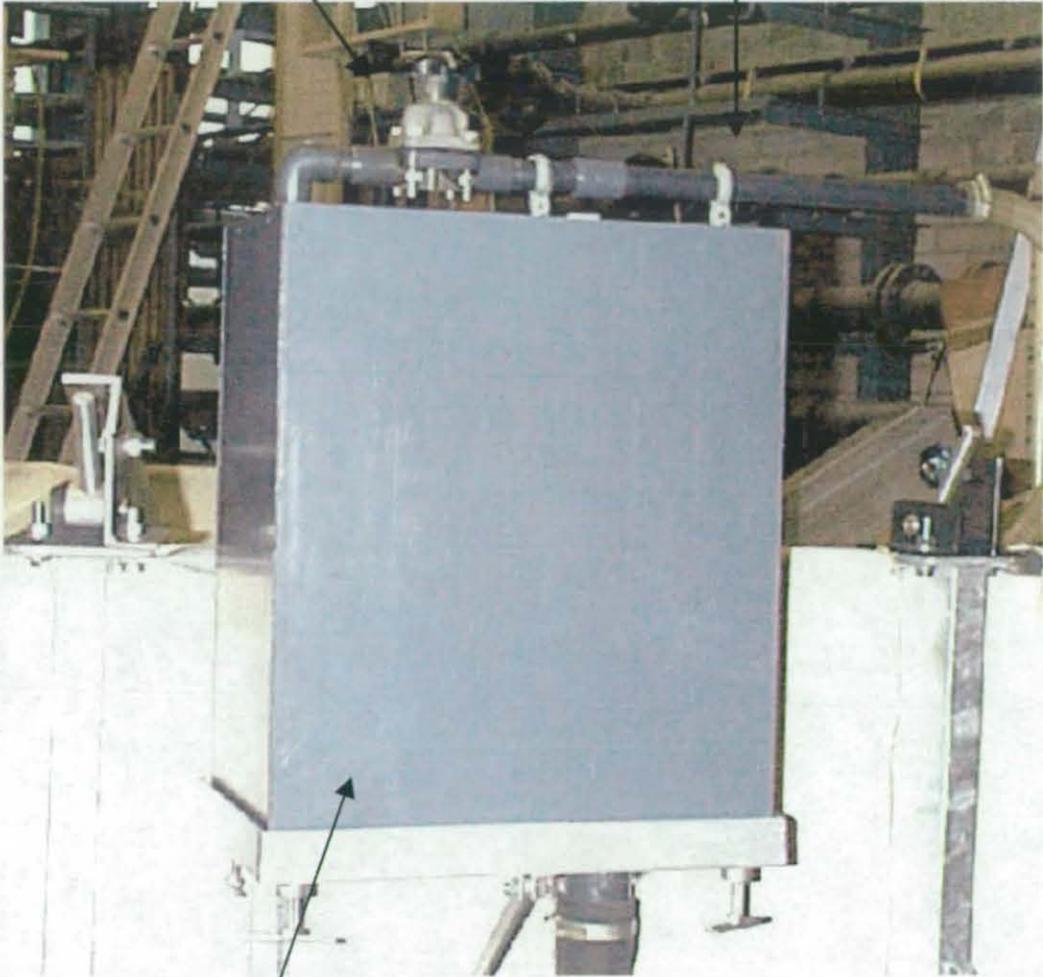
The box is fixed to the tank with a steel frame; since the outlet from the box is not directly over the washout valve, these two are connected with a flexible 50 mm pipe.

The design of the box is presented in detail in Drawings 10, 11, 12.

The box can be seen fixed on the tank in Picture 11.

25 mm diaphragm valve

25 mm inlet pipe



Flow control box

50 mm pipe (connected to
water distribution pipe)

Picture 11: Flow control box

5.8 MEDIA

5.8.1 Introduction

The media bed has a thickness of 0.75 m and is divided in two layers. The first layer (bottom layer) is 0.10 m thick and contains oversized polystyrene beads with a diameter of 10 - 12 mm; the second layer (top layer) is 0.65 m thick and contains small polystyrene beads of about 4 mm.

Traditional media such as gravel or broken stones and bricks are either placed directly on the filters' floor or on a false filter bottom. Since they are not buoyant, during normal operation of the filter they will stay submerged.

The use of polystyrene media presents some new problems. It must not only be ensured that the beads can not fall through the raised floor, but also that they can not float when the filter is filled with water as well.

The above problems can be resolved in two stages. First, ensure that the media bed is enclosed in a structure that does not allow the polystyrene beads to fall either through the bottom when the filter is empty or through the top when the filter is filled with water. Second, ensure that the media are not floating during normal operation. These two stages will be described in the rest of the chapter.

5.8.2 Media bed

The media will be placed on the raised floor described in 5.5.2. The openings of the galvanised mesh are 50 x 50 mm. It is obvious that the media can fall through the mesh, since the openings are too big.

Originally, it was considered to cover the floor with a finer mesh made out of a geogrid with openings around 3 mm. The disadvantage was that the floor does not have a close fit with the tanks' walls. The small media could still fall through the gap between the floor and the mesh.

The solution to the problem is to enclose the beads in bags made out of fishing net. The advantages of that are numerous:

- the gap between the floor and the tank's walls is no longer an issue, since the beads are kept inside the bag
- the bags can be easily placed in and taken out of the filter in case of maintenance, or in the case that the filter needs to be dissembled and transported to a new location

Two types of net are used, 6 mm mesh for the oversized and 3 mm mesh for the small beads. The bottom layer which contains the oversized beads consists of 6 bags. The top layer which contains the small beads is further divided into 3 sublayers and each sublayer consists of 11 bags containing 140 l each. The calculations of the dimensions of the bags can be found in annex 8. The number of bags was selected after various attempts were made to find the arrangement which gave the best possible fit.

The reason that the beads are divided into many different bags is that by placing the bags one next to the other, they will form a layer which will cover the filter's area. The bags are much larger than required to hold the beads so that they can change their shape and ensure a close fit with the tank's walls. Nevertheless, it is obvious that the points of contact between the bags can create a short circuit during the normal operation of the filter, since they will provide a path of least resistance through which the water can pass without getting filtered. This problem is overcome by using four layers; in that way between any two adjoining layers, the bags of the upper one are placed in such a way that they overlap the gaps between the bags of the lower layer.

5.8.3 Lattice for restraining media

Once the media bed is installed, it must be secured so that the beads will not float when water enters the filter. A galvanised mesh identical to the one used as a floor (see chapter '*Drainage*') is placed on top of the media. The floor is secured with a lattice which is attached to the tank's reinforcing frame. The uplift force from the

beads is thus transmitted through the lattice to the reinforcing frame to the base, as described in the chapter 'concept design'.

One unknown factor was the strength of the water tank. Since the tank was designed for water storage, it was not possible to predict whether the frame could support the extra forces from the polystyrene beads. It was thus decided to test the strength of the frame's vertical supports in the laboratory. The testing is described in annex 9. The support was tested for a force far greater than that anticipated and did not show any signs of failure.

The lattice will be immersed in water, so it is made out of aluminium which is resistant to corrosion. In addition, it is lightweight thus contributing only slightly to the filter's total weight.

The components of the lattice can be seen in drawings 13- 19. It can be divided to the following parts:

- the 11 - sided frame which is placed on the mesh on top of the media
- the struts which are fixed to the tank's frame and keep the 11 - sided frame submerged

The load from the beads is transmitted through the 11 - sided frame to the struts; since the struts are fixed on the frame of the tank, the total load is transmitted through the frame to the tank as planned.

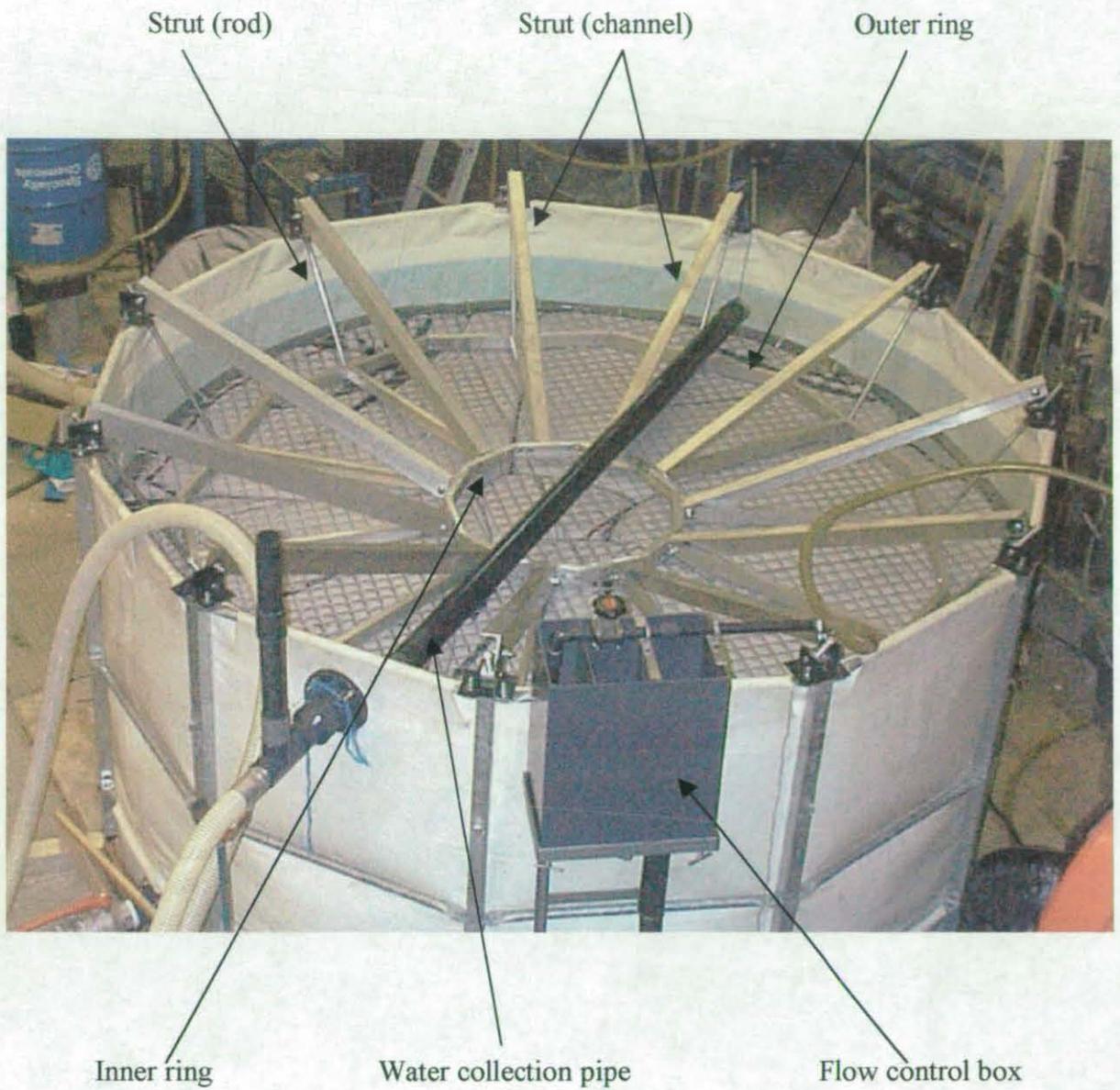
There are some important details in the design:

- the 11 - sided frame is composed of two 11 - sided 'rings'; the components of the rings are aluminium channels with a cross section of 50mm x 25mm x 3mm; the rings are interconnected with 11 aluminium channels of the same cross section
- in order for the ring to fit into the packaging boxes, it is divided into 11 identical pieces which can be bolted to each other; the connections between the various lengths of channels are either permanent with rivets, or detachable with bolts; the rivets and bolts are all stainless steel, in order to resist corrosion and prevent a reaction on the surface of contact between the aluminium and the rivets/bolts

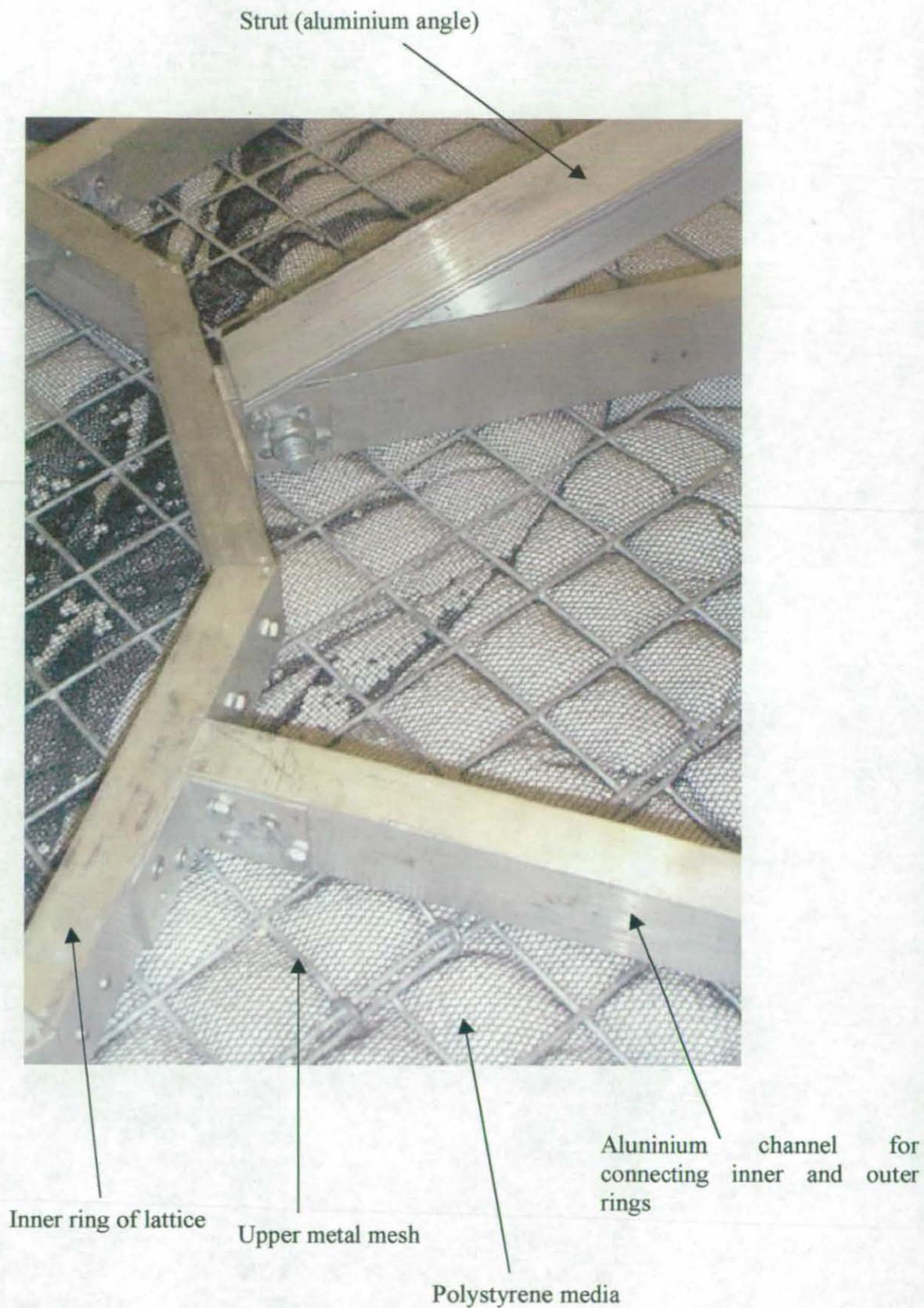
- the connections at both ends of the struts are pin jointed;
- the original design was to use only 11 struts. It was thought that if the struts' length was variable, the thickness of the filter bed could be varied as well. The strut was thus made out of a threaded aluminium rod, whose length could be changed by adjusting two nuts (see Annex 10.3). The rods were fixed on the outer ring. When the first design was tested, the internal 'ring' could not resist the upforce. It was thus decided that it was necessary to reinforce the lattice with additional struts.
- the selection of the material was to some extent based on the availability of the material in the stock of the civil engineering lab in Loughborough University; the reason being to use available material and avoid the additional expense of buying new material. Some components, such as the rods and the steel were designed first, followed by the calculations checking the resistance to various forces. As a result, some parts are over - designed, i.e. are too strong for their application.

The detailed design of the lattice is described in annex 10. The components of the lattice can be seen in detail in drawings 13 – 19.

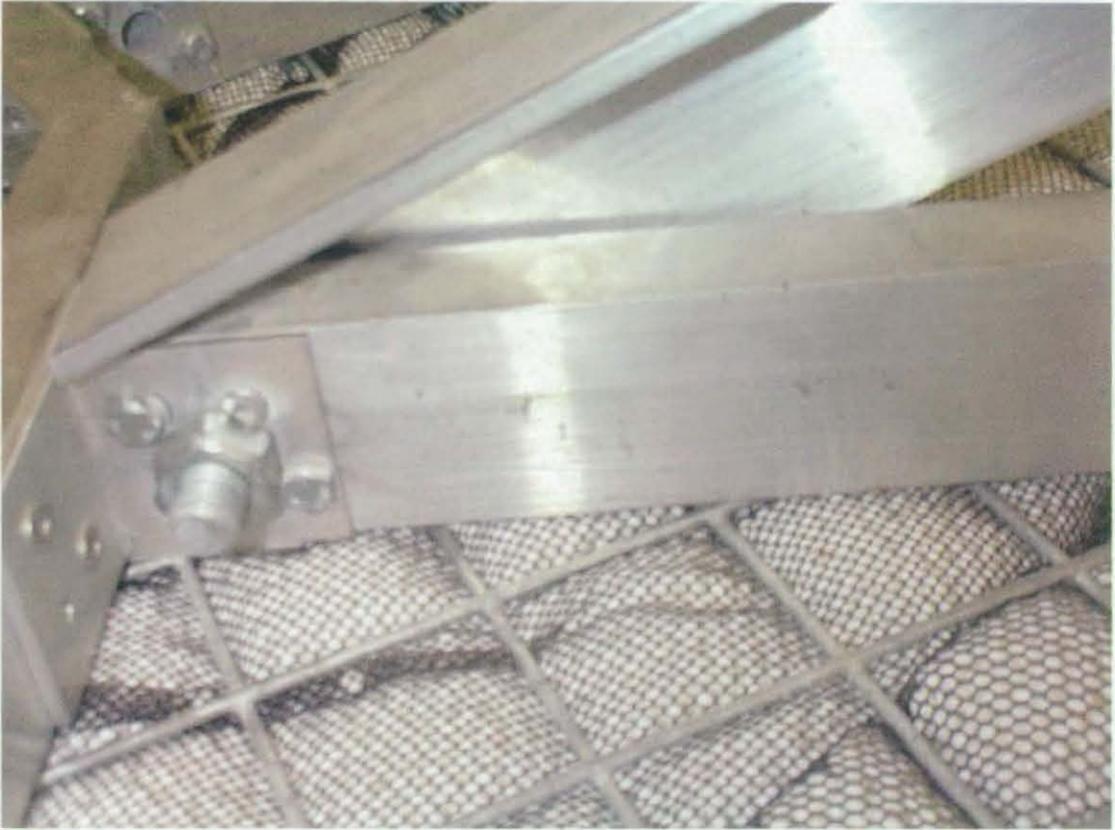
The lattice can be seen fixed to the tank in Picture 12; some of the components of the lattice can be seen in Pictures , 13, 14, 15 and 16. The bags with the media can be seen in Picture 17.



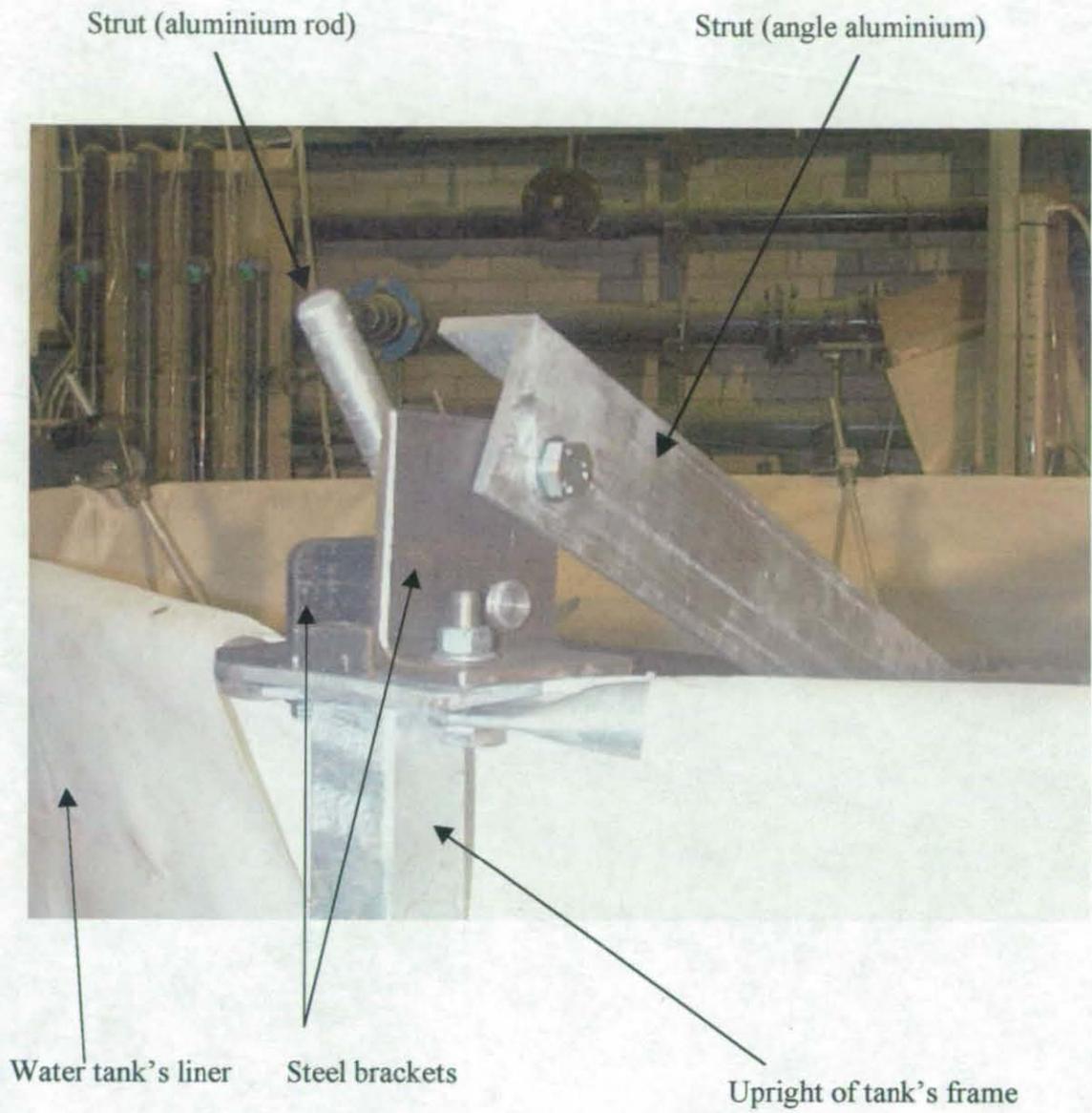
Picture 12 : Aluminium lattice fixed to the water tank



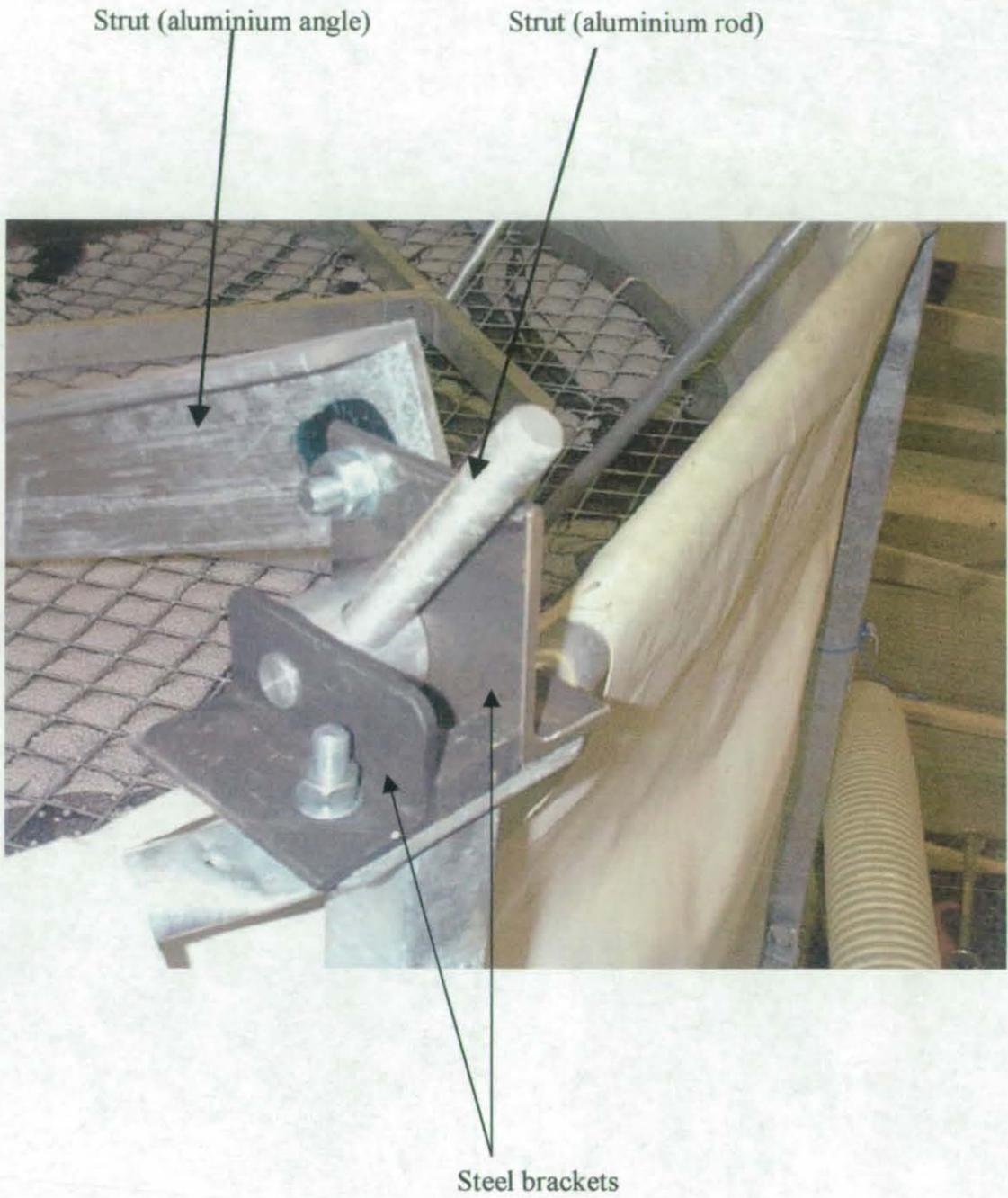
Picture 13 : Connection of aluminium angle strut to inner ring



Picture14: Connection of aluminium angle strut to inner ring



Picture 15 : Connection of struts to brackets



Picture 16 : Connection of struts to brackets (bis)



Picture 17: Layers of bags with polystyrene beads

6.1 PRESENTATION OF DISCUSSION

The performance of the filter can be assessed in the following categories:

- structural performance, where the effect of the upforce from the polystyrene beads on the filter's structure is observed
- hydraulic performance, where the performance of the inlet, outlet and drainage is examined
- ease of assembly and operation
- overall performance of the filter, i.e. performance as a portable unit

The beads were left submerged without interruption for at least 48 hours on three different occasions in order to observe the effects of the upforce from the beads; the filter was also left running for periods up to 8 hours in order to assess the hydraulic performance; it was then dismantled in order to observe the effects of the forces on the various components such as the raised floor, the drainage pipes and the base.

In order to facilitate the discussion on the structural performance, the water tank, the base and the lattice will be examined individually.

For the hydraulic performance, the flow control, the inlet, the media bed, the water collection and the drainage will be examined individually.

The filter's overall performance as a portable unit will be discussed in terms of weight and volume, ease of assembly and operation and maintenance.

6.2 STRUCTURAL PERFORMANCE

6.2.1 Water tank

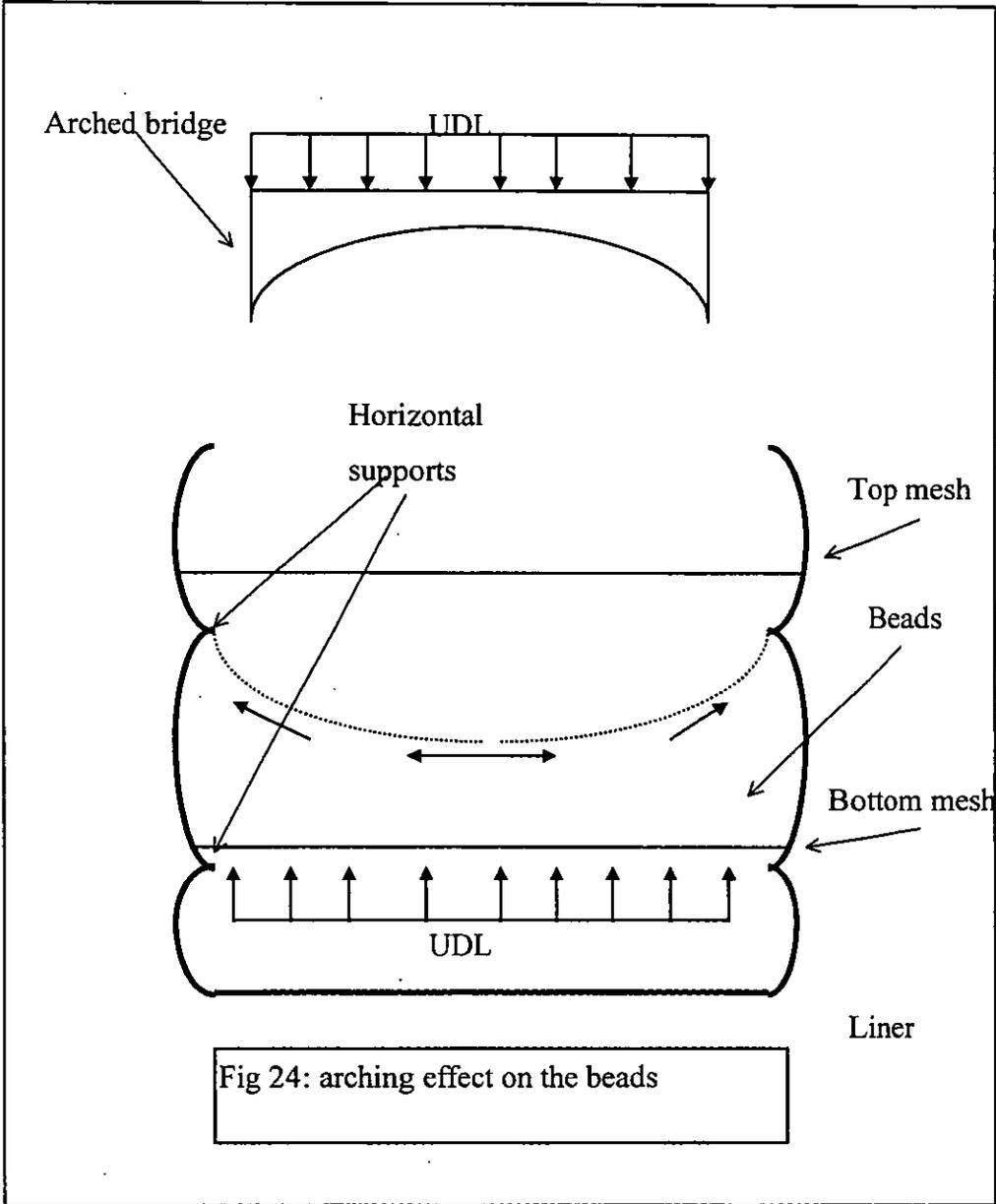
The frame and the liner did not show any signs of failure. Their performance is all the more satisfying because they supported forces that they were not designed for; the liner probably had to support forces other than the ones from the hydrostatic pressure of the water.

It can be argued that a part of the load from the beads is probably distributed on the liner of the water tank as well. First, since the beads are touching the tank's wall, there must be some friction between the wall and the beads; this friction is probably insignificant.

Nevertheless, there are probably more significant forces on the tank from the beads. When the tank is filled with water, the wall of the tank changes shape due to the pressure from the water. The liner is 'bulging' between the openings on the galvanised iron frame.

It can be assumed that the beads apply a uniform distributed load; due to this, there is probably an arching effect, similar to that of a bridge where the load on the bridge is transmitted through the arch to the ground. The arching on the beads can be imagined to be an arched bridge, only inverted, where some of the load is transmitted to the wall of the tank. The arching effect can be seen in fig 24.

It must be pointed out that the above assumptions are theoretical and can not be fully validated.



6.2.2 Base

During the normal operation of the filter, the floor did not seem to bend under the load from the beads.

When the filter was dismantled, no deformation of its components was observed.

The two types of plywood showed a similar performance, since they were both intact with no visible cracks.

When comparing the two types of plywood on the basis of weight, the advantage lies with the marine ply; the gain in weight is about 24 kg (for both layers of plywood).

When the comparison is based on the long term performance, then the advantage lies with the phenol - faced; it is stronger than the marine - ply and more resistant to water.

Since the filter is designed for use in emergencies and portability is a very important factor, the gain in weight is more important than the long - term performance. It can be argued that in the case that the filter is operational for an extended period of time, the users will have enough time to get a replacement for the plywood.

It must also be noted that the aluminium square sections are over designed; the assumption about the expected bending moment was over - conservative. A 50 x 50mm section would probably be sufficient, nevertheless the upper layer of plywood could be damaged since a smaller area of the edges of the pieces would be supported by the smaller section.

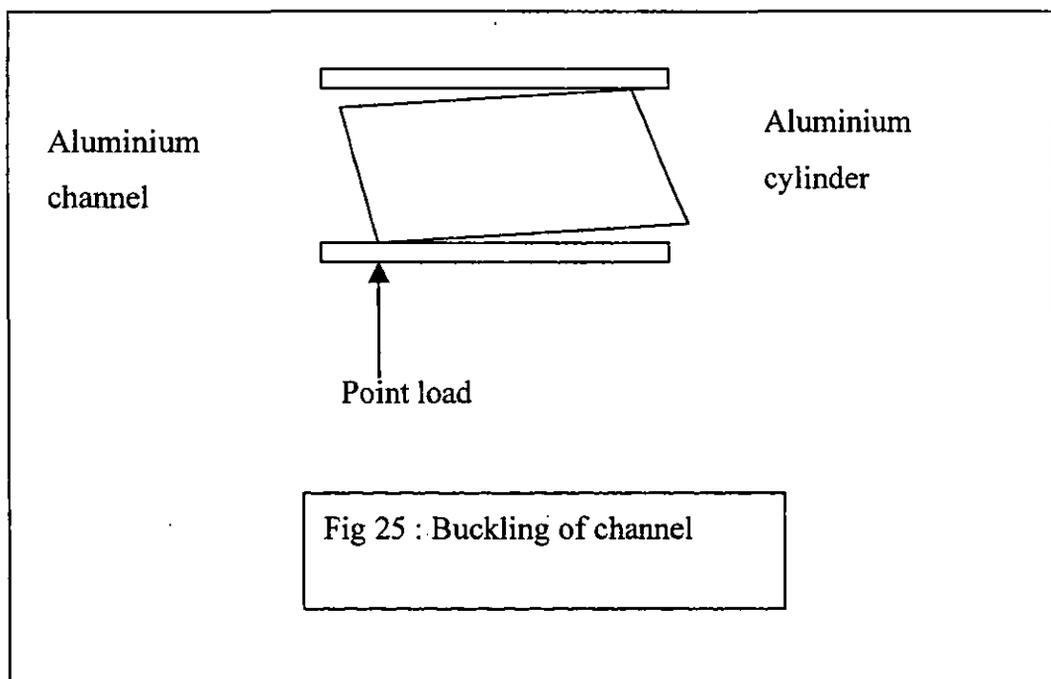
It was mentioned in 5.3.4.4 that in order to test the usefulness of the support (aluminium C channel) which is under the centre of gravity of the plywood, the support was omitted from 4 pieces of plywood, two of each type. The results showed no difference on the plywood pieces whether the middle support was used or not; nevertheless, the use of this aluminium support is recommended to prolong the long term performance of the plywood and assist with load distribution on uneven ground.

The L pieces showed signs of corrosion; this was expected, since they were not protected against corrosion. For the future, it is recommended to galvanise the L pieces in order to avoid corrosion and reaction between the aluminium and the steel; alternatively, the L pieces could be fabricated out of aluminium.

6.2.3 Lattice

The lattice resisted the upforce from the media. After the filter was drained, the lattice was disassembled and the members were all thoroughly checked and the following observation was made:

Some of the aluminium channels of the outer ring buckled locally at the point of contact with the rod; the reason was that the rod was slightly twisted, so the aluminium cylinder was in contact with the channel only on one edge. Consequently, the load was not distributed over a larger surface, but acted as a point load (fig 25). This problem can be avoided by ensuring that the cylinder is in contact with the channel over the cylinder's total length.



There were no signs of failure or deformation on the struts (rod and angles); they were oversized because the design was based on the assumption that the total load from the beads would be entirely transmitted through the lattice to the tank's frame. As it was explained in 6.2.1, a part of the load is probably transmitted to the liner of the tank, although the exact proportions are unknown.. In addition, it was assumed that each set of struts (rods and angles) would carry 75% of the total load, which is probably a very conservative assumption.

It was a conscious decision to oversized the lattice by assuming that all the load was transmitted to the lattice because it was not possible to predict how the lattice would actually behave until it was tested on a full scale. In addition, an oversized lattice can accommodate for mishandling or 'robust' handling from unqualified or inexperienced personnel on the field.

There are three necessary modifications to the lattice:

- one concerns the outer eleven - sided ring which is placed on the mesh on top of the beads; the mesh is at approximately 285 mm from the wall of the water tank; the part of mesh that is between the wall and the outer ring bends upwards under the load of the beads. If the ring were to approach the tank's wall at a distance of approximately 100 mm, the mesh would not bend.
- the second modification concerns the aluminium rod; since it has been decided that the height of the media bed will be fixed, there is no point in using the rod. The rod had been originally designed as such in order to make possible modifications on the height of the media bed. The rod should be replaced with a piece of aluminium angle such as the one fixed to the inner ring. Instead of using two brackets, a single bracket could be used for fixing both the angles which act as struts
- although the struts are oversized, the aluminium sections of the rings are probably undersized; a bigger section such as 75 x 50 mm could be used. Alternatively, the same section of 50 x 25 mm could be used, but with a thickness larger than 3 mm.

6.3 HYDRAULIC BEHAVIOUR

6.3.1 Flow control

The flow is adjusted by opening the valve on the flow control box and fixing the height of the water over the weir at 80 - 81 mm for a filtration rate of 0.75 m/h (annex 7).

The height of the water above the weir can be measured with the aid of the piezometer tube on the side of the box. The turbulence is supposed to be removed by the baffle in the first compartment thus providing a relatively 'calm' water surface before the weir at the position of the tube; consequently, if the water's surface is relatively calm then the level of water in the tube remains constant and the reading - thus the corresponding discharge - is accurate.

First compartment (before the weir)

During the filter run, it was noticed that the height of the water column in the piezometer remains undisturbed for heights less than 60 mm. When the height was set to about 80 mm, the level of the water in the piezometer made sudden 'jumps' of heights up to 5 mm. From table 7 in annex 7, it can be seen that the filtration rates which correspond to 80 and 85 mm are 0.74 and 0.85 m/h respectively.

The reason for the jumps is that there was turbulence in the first compartment resulting to a disturbance on the water surface. The 'jumps' of the water level in the piezometer reflect this disturbance.

If the reading of the piezometer is not constant, then the true value of the corresponding filtration rate could lie anywhere between 0.74 and 0.85 m/h.

Since the filtration rate can affect the filter's performance, it is obvious that an error in the flow measurement can lead to the filter running at a rate different than the design target of 0.75 m/h.

The excessive turbulence can be attributed to the dimensions of the box. As it has already been mentioned in section 5.7.3, the box has been deliberately under-sized, making a compromise between accuracy and weight/volume.

The only obvious modification which would eliminate the turbulence and improve the accuracy of the flow measurement would be to augment the dimensions of the box according to the recommendations in 5.7.3.

The question that has to be answered is whether it is worth constructing a heavier and bulkier flow - control box in order to acquire a very accurate flow measurement.

According to the experimental work with the polystyrene beads, the average turbidity removals for the filtration speeds of 0.75 and 1.0 m/h was 59 and 41 % respectively; this difference is quite important. There are no data for the turbidity removal at a speed of 0.85 m/h. This suggests that differences in filtration speeds could influence the removal rates.

Since the filtration rates of 0.85 and 0.75 m/h are relatively close, it could be assumed that the difference in turbidity removal would not be very important. Nevertheless, since there are no experimental data to support this assumption the worst case must be assumed, i.e. that the difference in filtration rates will have a negative effect in the turbidity removal.

Second compartment (after the weir)

The second compartment is designed to serve a dual purpose:

- collect the overflow from the weir and channel the water in the 50 mm inlet pipe
- monitor the headloss increase by the rise of the water level

During the filter run two problems were observed:

First, there are bubbles escaping from the inlet distribution pipe at the bottom of the tank. The bubbles escape from the first opening on the top of the pipe (this

opening was made to avoid trapped air in the pipes which would make them buoyant while the filter was filling up). The bubbles indicate that air is entering the inlet pipe through the 50 mm opening below the weir.

As it was explained in 6.5.2, the level of the opening is below the water level in the tank so that it is always under water. In theory, there should be no air entering the pipe. In practice, the water that overflows from the weir and falls freely in the second compartment creates significant turbulence and as a result air enters the pipe.

The second problem is that the surface of the water is disturbed; consequently, it is impossible to measure the changes in the height of the water in order to calculate the headloss.

In order to remove the air that enters the system and obtain an undisturbed surface, the turbulence must also be removed from the second compartment. This can be achieved by adding an adjacent compartment and separate the two by a baffle similar to the one in the first compartment (fig 26). The baffle will remove most of the turbulence; if the opening is moved to the last compartment, the surface of the water above the opening will be flat and no air will enter the pipe. In addition, the undisturbed surface will allow an accurate measurement of the changes of the height of the water due to headloss.

An additional compartment would mean that the total volume of the box and consequently its weight when filled with water would increase. Nevertheless, the additional weight can be considered to be negligible.

An alternative would be not to use a V notch weir as a flow measuring device at all. One other possibility would be the use of a venturi meter, but since such a modification would be significant, further research is recommended.

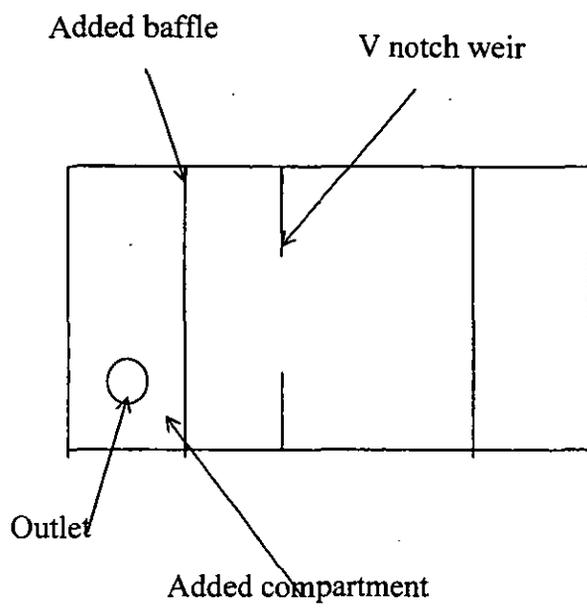


Fig 26: Added compartment in flow control box

6.3.2 Media

The media were delivered in an expanded state from the manufacturer.

The larger media were divided to six bags; the area of the floor was fully covered.

The smaller media were originally divided in three layers, with six bags in each layer. The result was unsatisfactory because the bags were not flexible enough to ensure complete coverage of the entire cross - section of the filter; there were large gaps between the bags and the bags and the tank's wall. Such gaps could create short circuits, since the water would follow the path of least resistance without getting filtered through the entire thickness of the media bed.

This problem was overcome by using eleven bags instead of 6 per layer; it was a lot easier to manipulate the bags and cover the entire cross - section. A possible short circuit due to the gaps between bags of the same layer was overcome due to the overlapping layers.

The eleven bags of any layer were placed in the filter in the following way: ten were placed next to the perimeter of the tank, leaving an open area in the centre one was placed in the centre, covering the gap

While the filter was running and the level of water was rising, it was observed that the beads moved because the bags were loosely filled. The beads of the lower layers which were getting submerged in water were trying to move upwards due to their buoyancy; the upforce from the submerged beads was thus transmitted to the beads in the higher layers.

Since the media bed is restricted by the tank's wall and the upper mesh, the beads could only move sideways; as a result, the beads were packed without leaving any gaps either between bags or between the bags and the tank's wall. The good packing could be observed at the top layer, which is uncovered. Even if it is not possible to observe the layers underneath, there is no reason to believe that the beads behaved in a different way.

The wall of the tank also changes its shape when filled with water; the wall moves outwards under the water pressure, thus augmenting the cross sectional area. The beads move to occupy the extra space. The fact that the beads move around and fill the gaps as well as the extra space due to the change in shape of the tank wall,

suggests that there must be an open space between the raised floor and the bottom of the media bed.

When the filter was drained for the first time, it was observed that the height of the media bed dropped slightly; this confirms the hypothesis that there were gaps in the media bed, which were filled when the water level was rising; consequently, it also confirms that the media moves to occupy all empty space thus eliminating possible short circuits.

The volume of the beads which go in the tank deserve attention. If there are not enough beads in the filter, then the thickness of the media bed will be less than the ideal 0.75m; on the other hand, if one tries to put too many beads in the filter, the top of the media bed will be too high and the lattice will not fit in place. Considering that the flexible tank changes slightly its shape - the tank's walls move outwards when full with water - it will be practically impossible to achieve a perfect fit.

When the beads were put in the filter for the first time, it was observed that the height of the media was higher than expected, i.e. it was between 0.80 - 0.85 m instead of 0.75 m. Nevertheless, it was observed that by applying pressure on the top of the beads while placing the bags in the filter -i.e. by placing the mesh on top of the beads and having one or two people walking on it - the beads were pushed against the tank's wall and forced it to move outwards; it was thus possible to fit the beads in the available space. It is recommended to proceed in a similar way when placing the beads in the filter.

6.3.3 Water collection

The water collection system is designed for a relatively uniform collection of the treated water. The water is collected in a perforated pipe and evacuated through a 50 mm pipe.

During operation, the water level on the filter is at approximately 1.4 m. At this height, there is an equilibrium between the water that enters the filter and the water that exits through the perforated pipe.

The problem of the air which is trapped in the outlet pipe could be eliminated by replacing the 50 mm T piece with a 75 mm, the water would thus fall in the pipe without trapping air due to the larger outlet. It is thus recommended to replace the outlet with a 75 mm T piece and pipe.

6.3.4 Drainage

The drainage is designed to serve a dual purpose:

- distribute the raw water
- 'clean' the filter by draining the water thus removing some of the accumulated solids

The distribution of raw water was tested in the following way:

The beads were removed from the filter in order to observe the drainage pipes. The filter was left running, and then a coloured dye was added in the incoming raw water; the dye exited from all of the openings of the distribution pipes; the dye also fully covered the area of the water. The raw water distribution was thus deemed satisfactory.

In order to drain the filter, the 25 mm valve which regulates the flow is turned off. Then the three 75 mm valves are opened one by one. The delay between the opening of the first and last valve is less than 10 sec, so for practical purposes it may be assumed that the valves were opened simultaneously. The valves are connected

with quick release couplings to three 75 mm flexible pipes, 6 m long . During drainage, the outlet of the pipes was 0.4 m below the level of the valves.

The filter was drained three times; the height of water at the beginning of the drainage was at approximately 1.4 m above the bottom of the tank; at the end of drainage it was at 0.3 m above the bottom of the tank. (Note: the level of the water in the tank was monitored by connecting a flexible transparent pipe to the 50 mm valve at the bottom of the tank; the pipe was then raised above the filter, so that the level of the water in the pipe corresponded to the level of the water in the filter; this pipe can be seen in picture 1.

Although the drainage must continue below the raised floor, the drainage speed after the water level has reached the floor is not important. As explained in 3.5, the filter must be drained fast in order to resuspend and transport the solids within the media. Consequently, only the time that it takes the water level to drop at the height of the raised floor at 0.3 m was recorded in order to calculate the average drainage speed.

The measurements for the average drainage speeds are presented in table 3. It must be noted that the drainage velocity of this experiment is influenced by factors such as the length of the pipes and the available head between the valves and the outlet of the pipes; the longer the pipes, the more headloss there is and the lower the outlet, the more head is available. The following average drainage velocities are indicative only for the specific conditions, i.e. flexible pipes 6 m long and outlet of pipes 0.4 m below the level of the valves.

Drainage cycle	Initial height (m)	Final height (m)	Difference (m)	Drainage time (s)	Average Drainage velocity (m/h)
1	1.40	0.30	1.10	158	25.0
2	1.37	0.30	1.07	155	24.8
3	1.39	0.30	1.09	157	24.9
Average					24.9

Note: *Initial height is the height of the water at the beginning of the measurement*

Final height is the height of the water at the end of the measurement

Difference = initial height - final height

Table 3: Average drainage velocities with media in the filter

The filter was also drained without containing any media. The results are presented in table 4.

Drainage cycle	Initial height (m)	Final height (m)	Difference (m)	Drainage time (s)	Average drainage velocity (m/h)
1	1.40	0.30	1.10	280	14.1
2	1.38	0.30	1.08	270	14.3
3	1.44	0.30	1.14	293	14.0
Average					14.1

Note: *Initial height* is the height of the water at the beginning of the measurement

Final height is the height of the water at the end of the measurement

Difference = initial height - final height

<p>Table 4: Average drainage velocities without media in the filter</p>

As it can be seen by comparing the two tables, the average drainage velocity in the filter was higher when the filter contained the media. This can be explained by the fact that when the filter contains the beads, they take a part of the volume that the water occupies; there is then less water to be drained and consequently the level of water in the tank drops faster.

In the same time, the beads are responsible for some resistance to the water as it drops, thus slowing the drop of the water level.

The average drainage velocity of approximately 14 m/h that was achieved is satisfactory, since it is close to the target value of 20 m/h. Nevertheless, the water that was used for the experiments was not turbid; it is not possible to estimate how the drainage velocity will be affected in the filter run with turbid water which will result

in an accumulation of solids within the pores of the media. It is safe to assume that the resistance to the water will increase thus reducing the drainage velocity. On the other hand, since the majority of the solids is expected to accumulate at the upper layer of media above the drainage, it is envisaged that the majority of the solids will be flushed out in the very beginning of the drainage process without affecting significantly the drainage velocity. In any case, only a field trial with turbid water can answer such questions.

The average velocity is useful for comparing similar filters; It is easy to calculate on the field, because the only readings which are necessary are the height of the filter bed and the time that it takes for the water level to drop. By taking intermediate measurements during the drainage process, it is possible to measure the variations of the drainage velocity during the whole process.

The results of the drainage are presented in table 5. The drainage velocity drops with time because the water level, thus the available head, drops as well.

HEIGHT (m)	DROP (m)	TIME (sec)	VELOCITY (m/h)
1.05	0.05		
1.0	0.1	8	45
0.9	0.1	9	40
0.8	0.1	9	40
0.7	0.1	10	36
0.6	0.1	11	33
0.5	0.1	11	33
0.4	0.1	13	28
0.3	0.1	17	21

Note: Initial height of measurement is 1.05 m (top of media)

Final height is 0.3 m (bottom of media)

DROP = drop of the water level

Time = time it takes for the corresponding drop

VELOCITY = drainage velocity which corresponds to the specific part of the drainage

Table 5: Intermediate drainage velocities

6.4 PERFORMANCE OF THE FILTER AS A PORTABLE UNIT

6.4.1 Weight and volume

The weights of all the items that are part of the filter are presented in annex 11. The weights of the components are also grouped according to the main components of the filter, i.e. the water tank, the base, the flow control box, the drain, the water collection, the lattice and the beads; they are presented in table 6.

COMPONENT	WEIGHT	COMPONENT % of total weight
water tank	130.6	16%
base	189.15	23%
flow control box	21.95	3%
Drainage	91.6	11%
water collection	13.6	2%
lattice	94.38	11%
media	199.95	24%
packaging	80	10%
TOTAL WEIGHT	821.23	100%

Table 6: weights of major parts

Weight & volume of filter without beads

The total weight of the filter without including the beads is 541.28 kg.

The components of the filter (without counting the beads) can fit in two boxes of dimensions 1.2x1.6x0.8 m, which correspond to a total volume of 3.07 m³. The weight of the filter is almost equally distributed between the two boxes.

It can be assumed that the weight of the packaging for the boxes are 40 kg each (including the palettes); the total weight of each box is therefore 300 + 40 = 340 kg.

Weight & volume of beads

It is assumed that the beads will be packaged in the unexpanded form. The expansion ratio for the beads with a 4 mm diameter is approximately 16/1 (Watson 1997); this means that 1 litre of unexpanded beads corresponds to 16 litres of expanded beads with a 4mm diameter. The expansion ratio for the bigger beads with a 10 mm diameter is approximately 40/1.

The filter contains about 4.6 m³ of 4 mm diameter beads and 0.7 m³ of 10 mm beads. Using the expansion ratio, the unexpanded beads which correspond to the 4 mm and 10 mm beads are 0.287 m³ and 0.0175 m³ respectively.

A total of 0.3 m³, of unexpanded beads must then be included in the kit.

The density of the unexpanded beads is 631.5 kg/m³, thus the weight of 0.3 m³ is 631.5 x 0.3 = 189.45 kg.

Adding the results for weight and volume for the filter and the beads, the total weight and volume for the unit is:

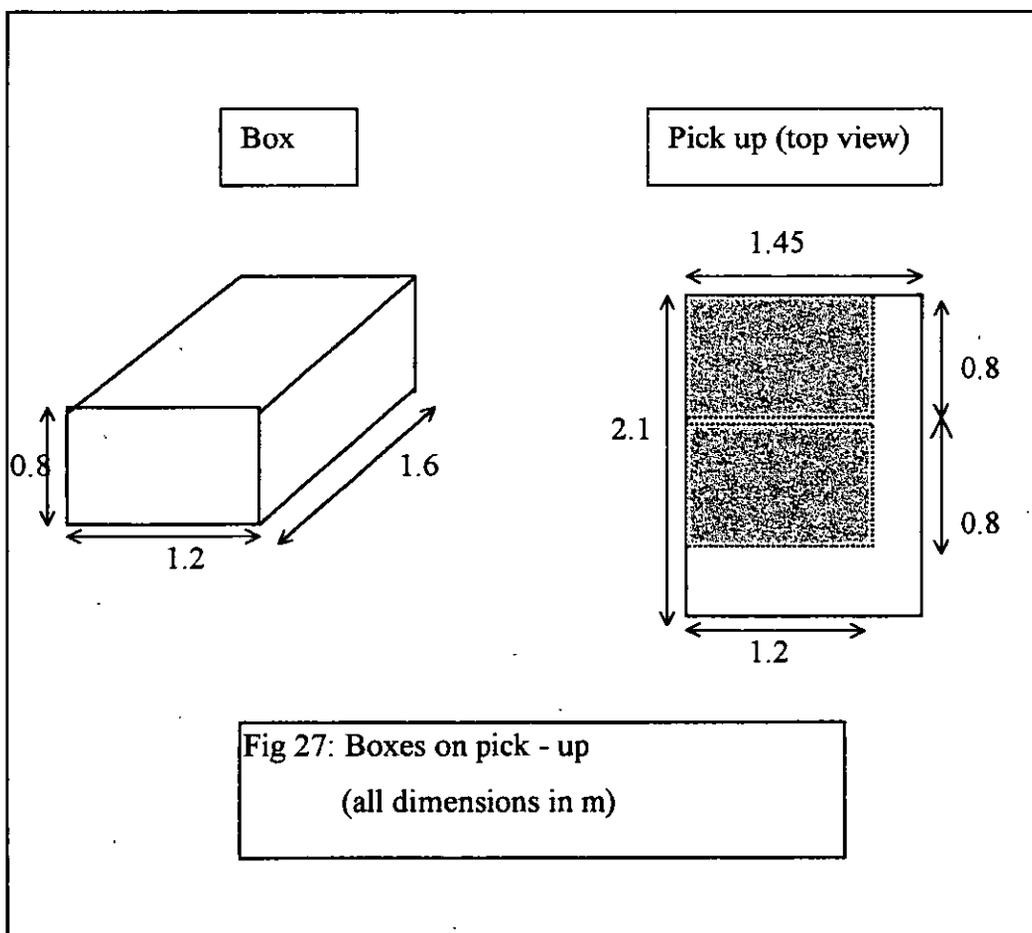
Weight: 631.78 + 189.45 = 821.23 kg

Volume: 3.07 + 0.3 = 3.37 m³

The weight and dimensions are well within the target values of 1000 kg and 1.45x1.1x 1.5 m respectively (4.2.2 & 4.2.3):

- the total weight of the unit is less than 1000 kg, thus it can be transported all at once with a pick - up
- the boxes can all fit in the back of pick - up, as it can be seen in fig 27.
- the unexpanded beads can fit around the boxes in the back of a pick - up

The only problem lies with the individual weight of the boxes, which is 340 kg, heavier than the 300 kg of the target; this problem though is considered to be of low importance, since the assumption that each person can carry 50 kg is quite arbitrary; in the worst case, an extra person could be added to the original six.



6.4.2 Ease of assembly

It took approximately 5 hours for the assembly of the filter. Two persons were involved in the assembly; one was the author who knew well how to proceed and the other was a person that had never worked before with the filter.

The fixing of the various bolts was particularly time consuming; the fact that some of the bolts (on the upright and on the rings of the lattice) had wingnuts simplified the assembly.

There were no significant problems in the assembly; the main point that must be kept in mind in order to keep the assembly time low is that during packaging, as many components as possible have to be already assembled, as long as they can fit in the boxes. For example, the liner must be fitted with all the flanges; and the various fittings must be fixed on the pipes.

In the author's opinion, the assembly time could be reduced significantly if more people are involved in the assembly, for example four people in total. The most important factor which guarantees a fast and simple assembly is to produce a manual that explains clearly the entire procedure (see 7.5, "Recommendations for future work").

6.4.3 Operation and maintenance

The operation of the filter is supposed to be very simple; all that one has to do is open the valve in the inlet box, adjust the flow of the water as registered on the piezometer and leave the filter running.

In practice, the only problem was the fact that the piezometer was not giving an accurate measurement due to the turbulence in the box; if a person on the field is faced with that situation, he would probably be confused since he would not know whether the filter was running at the right velocity or not.

The maintenance of the filter consists of monitoring the headloss in the inlet box and draining the filter when necessary:

- The drainage part is very simple; all one has to do is open the drainage valves, wait about 3 minutes , close the valves and return the filter to service.
- The monitoring of the headloss is problematic again due to the inlet box; due to the excessive turbulence in the second compartment of the inlet box, it is not possible to get a consistent reading of the level of water.

In conclusion, operation and maintenance are very simple as long as the inlet box is modified so that it functions properly.

One aspect of the operation which deserves special consideration is the disposal of the washwater during drainage; there are about 5 m³ of water that have to be evacuated in a period of about 3 minutes. Such a volume of water on the field needs to be evacuated safely in order to avoid problems such as soil erosion, stagnated water around the filter which can become a breeding site for insect vectors, etc. Potential users of the filter must be made aware of this problem in the instruction manual which will accompany the kit.

7.1 STRUCTURAL PERFORMANCE

The structural performance of the filter is satisfactory; all the components supported the load from the upthrust of the beads. The assumptions that were made for the design of the lattice were conservative, because they did not take into account the possibility that a part of the load is transmitted to the liner of the water tank. The design of the base was also conservative because the assumptions for the effect of the bending moment on the components of the base were conservative as well.

Nevertheless, it is not recommended to change the components of the base because the gain in weight would not be important enough to justify the risk of reducing the strength of the components. In addition, increased robustness is beneficial during transport and assembly by unqualified personnel.

Two minor changes in the design are recommended:

- replace the aluminium rods that hold the beads down with sections of angle aluminium
- augment the diameter of the eleven - sided ring on top of the media bed so that the top mesh does not bend under the load from the beads.

Perhaps the most important inconvenience for the design resulted from the fact that the water tank had an uneven number of sides (eleven); the design of the lattice would have been more straightforward – thus gaining in simplicity and reducing the weight- with an even sided tank. For the future it is recommended, if possible, to design the roughing filter around an even sided tank.

7.2 HYDRAULIC PERFORMANCE

The hydraulic performance of the drainage and the water collection is satisfactory.

In contrast, the performance of the inlet structure is not satisfactory. The main problem is the turbulence in the flow control box because the dimensions of the box are smaller than the ones recommended in literature. As a result, the measurement of the flow and the corresponding filtration velocity are not accurate.

In addition, the turbulence traps air in the inlet pipe, resulting into air bubbles escaping from the raw water distribution.

It is probable that if the filter runs at a filtration rate different than the design rate of 0.75 m/h, it will have a negative effect on the removal efficiency of the filter.

It is therefore recommended to built a bigger flow control box whose dimensions conform to the theoretical values presented in section 6.5.3. Alternatively, a different method of flow control could be considered.

7.3 PERFORMANCE OF THE FILTER AS A PORTABLE UNIT

The overall performance of the filter as a portable unit is deemed satisfactory.

The total weight of the kit is about 821 kg; the weights of the major parts of the filter can be seen in the following table.

COMPONENT	WEIGHT	COMPONENT % of total weight
water tank	130.6	16
base	189.15	23
flow control box	21.95	3
Drainage	91.6	11
water collection	13.6	2
lattice	94.38	11
media	199.95	24
packaging	80	10
TOTAL WEIGHT	821.23	

The total volume of the kit is approximately 3.4 m³. The filters components are divided in two boxes with dimensions 1.6 x 1.2 x 0.8 m. The beads are packaged separately in their unexpanded form.

Both the total weight and volume are within the target values. All of the kit can be loaded on a pick - up for transport.

The only problem was that the two boxes which contain the components of the filter are slightly heavier than the target 300 kg, so 6 people are probably insufficient for moving each box; nevertheless, that problem is not considered important, since it could be solved with the addition of extra people for the moving.

The assembly of the filter was also satisfactory; the filter was assembled by two people in about five hours, without having any particular problems. The assembly time could be reduced if more people participated.

The operation of the filter is very simple. The only problem is again related to the flow control box, since the excessive turbulence does not allow an accurate reading of the headloss as well as the water level in the piezometer.

People with specific knowledge on how to assemble and operate the filter may not be available on the field. An instruction manual which explains in a simple way the assembly and operation of the filter will be a valuable tool in the hands of the people that receive the kit on the field. Simple diagrams and figures should be preferred over text in order to transcend language barriers.

7.4 FINAL CONCLUSIONS

The design of a portable upflow roughing filter using polystyrene beads as filtering media can be considered successful. Some modifications are necessary, notably on the flow control.

The initial constraint of using a 11 sided water tank complicated the design, notably for the lattice used to hold the polystyrene media down.

The proposed portable unit can be considered an attractive proposal to organisations which work in emergencies.

7.5 RECOMMENDATION FOR FUTURE WORK

An instruction manual describing in a simple way the assembly and operation will be invaluable when the filter will be dispatched to the field.

In order to complete the evaluation of the filter, it is necessary to test its turbidity removal efficiency with turbid surface water; the removal efficiency should

be evaluated (if possible) during periods of low and high turbidity, depending on seasonal variations.

The evaluation of both the instruction manual and the performance of the turbidity removal on the field will permit a complete "field" validation of the filter.

The filter must be dispatched on the field, preferably to a site where alternative turbidity removal methods such as chemical coagulation and flocculation are already in practice, in order to compare these methods to roughing filtration.

For future work, it would be interesting to combine a sedimentation technique with the roughing filter, i.e. before the inlet.

Last but not least, a research of water tank manufacturers should be initiated in order to evaluate the possibility of constructing a similar tank with an even number of sides; such a tank would simplify the design of the lattice, thus gaining in ease of construction, ease of assembly, and possibly weight.

ANNEX 1: CALCULATION OF THE FILTER'S FLOW RATE

The water tank's inside diameter is assumed to be 3 m. Its effective cross-sectional area (A) is:

$$A = \pi d^2/4 = 3.14 \times (3 \text{ m})^2/4 = 7.065 \text{ m}^2$$

The filtration rate v_f is assumed to be 0.75 m/h.

The flow rate (Q) is thus:

$$Q = A \times v_f = 7.065 \text{ m}^2 \times 0.75 \text{ m/h} = 5.298 \text{ m}^3/\text{h},$$

or approximately $5.3 \text{ m}^3/\text{h} = 1.47 \times 10^{-3} \text{ m}^3/\text{s} = 1.47 \text{ l/s}$

Assuming that the filter is running 24 hrs/day, the daily quantity of treated water is

$$5.3 \text{ m}^3 \times 24\text{h} = 127.2 \text{ m}^3/\text{day} = 127.2 \times 10^3 \text{ l/day}$$

Assuming that the target value for one person in an emergency situation is 15 l/day, then the filter can treat enough water for $127.2 \times 10^3 / 15 = 8480$ people.

Assuming that the quantity that corresponds to each person is 5 l/day, then the filter can treat enough water for $127.2 \times 10^3 / 5 = 25440$ people

ANNEX 2: MEASUREMENT OF THE UPFORCE FROM THE BEADS

A. Set up of the experiment

In order to estimate the upforce from the beads while immersed under water, we can calculate the upforce from a small known quantity and extrapolate the results on the full scale. The set up of the experiment can be seen in fig 28.

As it can be seen, the weight of an object under water can be measured with a balance. When compared with the weight outside the water, the difference in weights can be attributed to buoyancy.

In order to measure the force that the beads can produce, 2 litres of beads are enclosed in a mesh bag; in order to keep the bag immersed, it is attached to a metal basket; the following measurements are then taken:

- the weight of the beads and the basket under water
- the weight of the basket without the beads under water

The difference between the two measurements can be attributed to the presence of the beads.

B. Results

In detail, the measurements were the following:

- weight of basket and beads under water = 2.577 kg
- weight of basket without beads under water = 3.647 kg

Difference: $3.647 - 2.577 = 1.07$ kg for 2 litres or 0.535 kg for 1 litre of beads.

In terms of force, that corresponds to $0.535 \text{ kg} \times 9.81 \text{ m/s}^2 = 5.25 \text{ N}$.

Thus 1 litre of beads when immersed under water can produce a force of 5.25 N.

Considering that the area of the tank is

$$A = \pi \times \text{radius}^2 = 3.14 \times (1.5\text{m})^2 = 7.065 \text{ m}^2$$

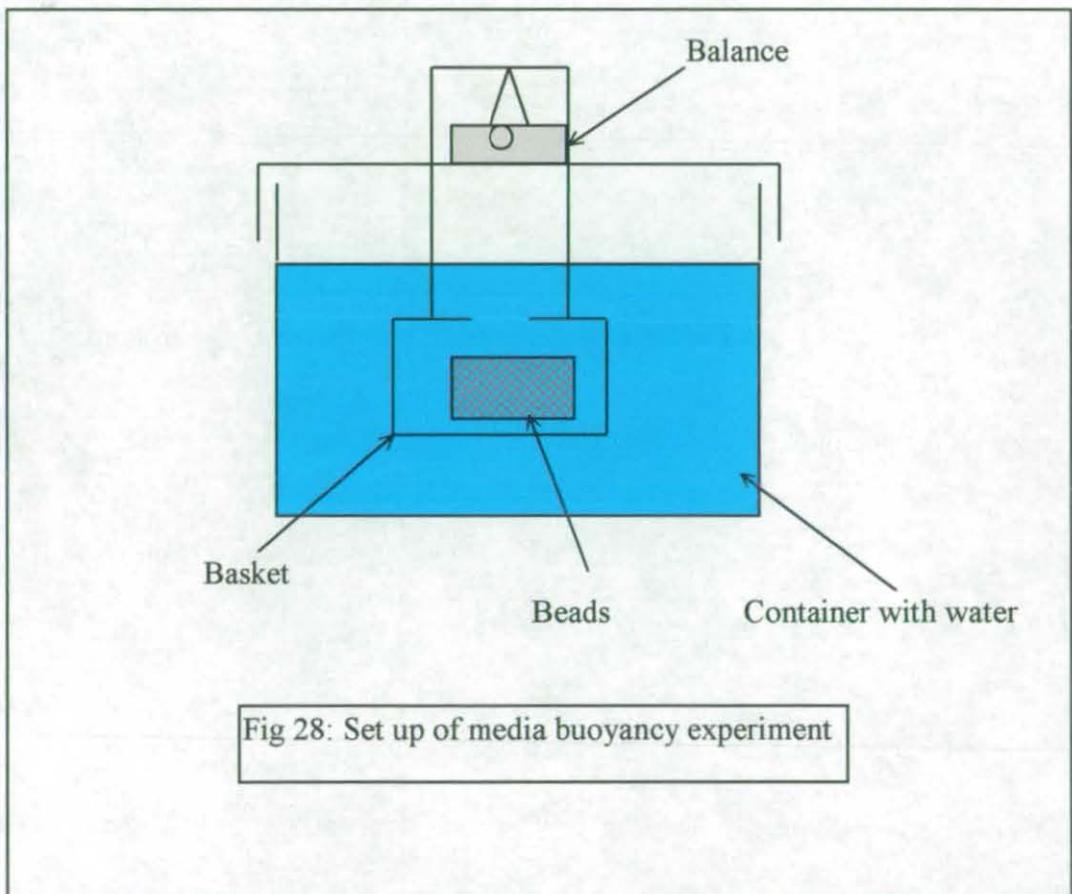
and the height of the media bed is 0.75 m, then the volume of the beads in the tank is:

$$7.065 \text{ m}^2 \times 0.75 \text{ m} = 5.298 \text{ m}^3, \text{ or about } 5300 \text{ litres}$$

It is obvious that if 1litre of media can produce 5.25 N, then 5300 litres can produce

$$5.25 \times 5300 = 27825 \text{ N} = \mathbf{27.8 \text{ kN}}$$

(Note: $27.8 \text{ kN} / 9.81 \text{ m/sec}^2 = 2834 \text{ kg}$)



ANNEX 3: DESIGN OF ALUMINIUM SQUARE SECTION FOR BASE

The estimated total load from the beads is 27.8 kN (annex 2). It is assumed that the load is distributed equally between the eleven uprights; consequently each upright will have to support $27.8 \text{ kN} / 11 = 2.5 \text{ kN}$. If a safety degree of 1.6 is inserted, the design force becomes $2.5 \times 1.6 = 4 \text{ kN}$.

Two forces are acting on the aluminium section:

- the estimated upforce of 4 kN, transmitted through the leg on the point of connection with the 'L' piece;
- the force from the weight of the tank, transmitted through the plywood on its entire length.

It is assumed that the sides of the tank will lift slightly due to the upforce from the beads. This will increase the distance between the point of contact of the upforce and the last point of contact with the bottom of the tank.

The above situation is similar to a cantilever beam with a concentrated load at its end. The design is based on the books by L.P. Bowen (structural Design in Aluminium) and The Shapemakers (aluminium extrusions - a technical design guide).

The aluminium alloy of choice is Alloy 6063, Temper T6. This is the most widely used alloy used in architectural members, road transport etc.; it has high corrosion resistance and good surface finish. T6 denotes the strongest temper available.

We assume that the maximum length of the beam between the point of the load's application and the point where it is fixed (point of contact with bottom of tank) will be 300mm.

Maximum bending moment = $4 \text{ kN} \times 300 \text{ mm} = 1.2 \times 10^6 \text{ N mm}$.

Maximum deflection $\delta_{\max} = WL^3/3EI_x$ (1)

where

- W is the applied load, i.e. 4 kN
- L is the length of the beam, i.e. 300 mm
- E is the Elastic Modulus, which is 65500 N/mm²
- I_x is the moment of inertia of the I axis

Solving (1) for I_x, we get:

$$I_x = WL^3/3E\delta \quad (2)$$

Substituting the values for W, L and E, we get:

$$I_x = 549618 \text{ mm}^4/\delta \quad (3)$$

The recommended deflection/span factor is Span/200 (aluminium extrusions, 1991); in this case, the maximum deflection is 300 mm/200 = 1.5 mm. Substituting this value in (3), we get the value for the minimum allowable I_x, which is

$$I_x = 549618/1.5 = 366412 \text{ mm}^4, \text{ or } 0.807 \text{ in}^4.$$

In Bowen (66) we can find from the table of properties of rectangular hollow sections that I_x of 0.807 in⁴ corresponds to a square hollow section of

$$62.5 \times 62.5 \times 2.5 \text{ mm}$$

Next, the maximum bending stress is calculated:

$$\text{Maximum bending stress} = \text{Max. bending moment} / Z_x \quad (4)$$

$$\text{For the section mentioned above, } Z_x = 0.716 \text{ in}^3 = 12519 \text{ mm}^3$$

Substituting the values in (4), we get that

$$\text{Max bending stress} = 9.6 \times 10^5 \text{ Nmm} / 12519 \text{ mm}^3 = 76.6 \text{ N/mm}^2.$$

Since the allowable stress levels are 96 N/mm² (BS CP118), the above section is below the allowable limits.

Due to the concerns about the plywood mentioned in 6.2.2, a box section of 75 x 75 x 3 mm can be selected.

ANNEX 4: DESIGN OF BOLTS FOR 'L' PIECE

The up force from the beads was calculated to be 27.8 kN. It is assumed that the load is distributed equally between the eleven uprights; consequently each upright will have to support $27.8 \text{ kN} / 11 = 2.5 \text{ kN}$. If a safety factor of 1.6 is inserted, the design force becomes $2.5 \times 1.6 = 4 \text{ kN}$.

Two 8 mm 'ordinary' ('black') grade 4.6 bolts are used to connect the two pieces. Two holes are drilled through the leg and the 'L' piece. The bolts are secured with wing nuts.

The design forces on the bolts are $4/4 = 1 \text{ kN}$

The possible failure on the bolts can be from the shear force. Specification for 'ordinary' bolts is covered by BS4190, and use of ordinary bolts is dealt with in BS5950 CL 6.3.

The connection between the L piece and the upright can be seen in fig 29.

CHECKS

Bolts

- Shear capacity

According to BS4190, the shear capacity P_s of a bolt should be taken as

$$P_s = p_s A_s \quad (1)$$

where

p_s = shear strength of the bolt = 160 N/mm

A_s = is shear area = 36.6 mm²

From (1) $\Rightarrow P_s = 160 \text{ N/mm}^2 \times 36.6 \text{ mm}^2 = 5.85 \text{ kN} > 1 \text{ kN}$, so shear is OK

- Bearing

$$P_{bb} = p_{bb} d t = 435 \times 9 \times 3 = 11.7 \text{ kN} > 1 \text{ kN}, \text{ thus bearing is OK}$$

Where

P_{bb} = bearing capacity

p_{bb} = bearing strength = 435 N/mm²

d = diameter of the opening = 9 mm

t = thickness of the web = 3 mm

Connected parts

- Bearing capacity

$$P_{bs} = p_{bs} d t = 460 \text{ N/mm}^2 \times 9 \times 3 = 12.42 \text{ kN} > 1 \text{ kN}, \text{ thus bearing is OK}$$

Where

P_{bs} = Bearing capacity

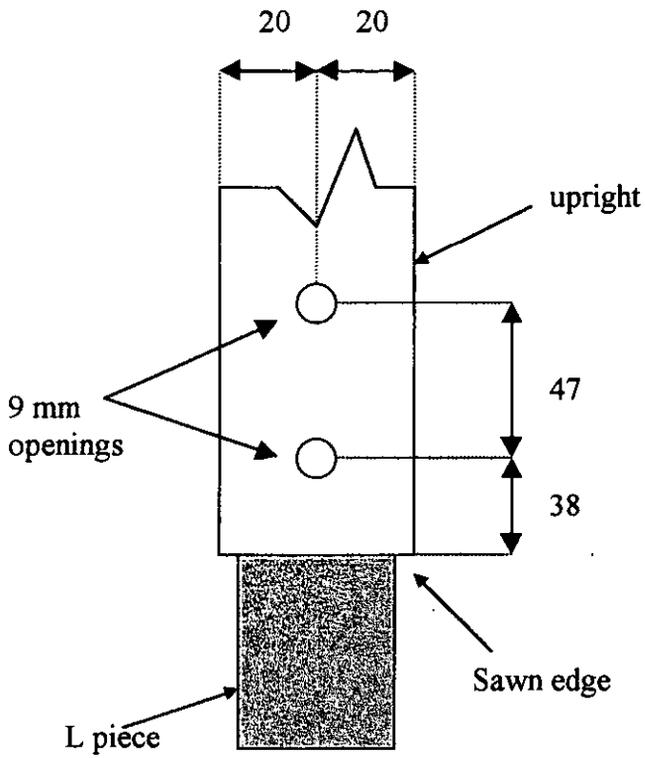
p_{bs} = bearing strength = 460 N/mm²

d = diameter of the opening = 9 mm

t = thickness of the web = 3 mm

- Shear

$$\text{Minimum edge distance} = 1.25 D = 1.25 \times 9 = 11.25 \text{ mm} > 38 \text{ mm}, \text{ thus shear is OK}$$



Section AA'

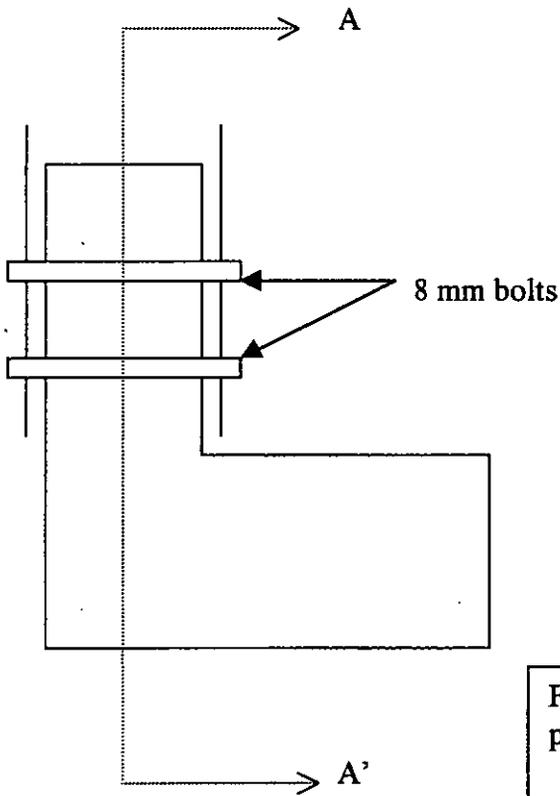


Fig 29 : Connection of L piece to upright

ANNEX 5: DESIGN OF MANIFOLDS

A. Design criteria

When the filter is under normal operation, the height of the water is expected to be at approximately 1.3 m from the bottom. During drainage, the objective is to achieve an average drainage speed of 20 m/h; The high speed is critical until the water reaches the bottom of the raised floor at 0.3m.

B. Theoretical calculation

(Note: the following calculations are based on the recommendations in Galvis et al. 1993).

The flow velocity during draining is assumed to be $v = 20$ m/h.

The area of the filter is approximately $A = 7.065$ m².

The total output of the system is:

$$\diamond Q_T = v \times A = 20 \text{ m/h} \times 7.065 \text{ m}^2 = 141.3 \text{ m}^3/\text{h}, \text{ or } 141.3 \times 10^3 / 3600\text{s} = 39.25 \text{ l/s}$$

Assuming that there will be three laterals (pipes) for the outlet, the output per lateral is:

$$\diamond Q_L = 39.25 / 3 = 13 \text{ l/s}$$

Assuming an opening size of diameter $d_o = 10$ mm and a flow velocity of 5 m/s per opening, the discharge per opening is

$$\diamond q_o = v_o \times A_o = 5 \text{ (m/s)} \times 78.5 \text{ mm}^2 = 392.5 \text{ mm}^3/\text{s} = 0.392 \text{ l/s},$$

where A_o is the area of the opening, $A_o = \pi d_o^2 / 4 = 78.5 \text{ mm}^2$.

The necessary number n of openings per lateral is

$$\diamond n = Q_L/q_o = 13/0.392 = 33.16, \text{ or approximately } n = 33 \text{ openings}$$

According to the theory, the diameter of the lateral can be calculated by using the formula:

$$\diamond d_L = (2n)^{1/2} \cdot d_o = (2 \times 33)^{1/2} \cdot 10 \text{ mm} = 81 \text{ mm}$$

As it has already been explained in section 6.3.3, the pipes which can be used can not be greater than 75 mm. The cross sectional area of the pipe is:

$$\diamond A_P = \pi d_p^2/4 = 3.14 \times 76^2/4 = 4534.1 \text{ mm}^2$$

The ratio between the combined surface of the openings and the surface area of the filter is:

$$\diamond n \cdot A_o/A_P = 33 \times 78.5/4534.1 = 0.57$$

When compared to the recommended range of values from 0.3 to 0.5 in table 2, the value of 0.57 is slightly out of that range. This is attributed to the fact that the diameter of the selected pipe is smaller than the theoretical one.

Note: If the three laterals were to be connected to a main, the diameter of the main d_M could be calculated by using again the formula

$$\diamond d_M = (2n)^{1/2} \cdot d_L = (2 \times 3)^{1/2} \cdot 87 \text{ mm} = 213 \text{ mm.}$$

ANNEX 6: CALCULATION OF FLOW IN WATER COLLECTION PIPE

The filter's flow rate is:

$$Q = 1.47 \times 10^{-3} \text{ m}^3/\text{s} \text{ (Annex 1)}$$

The inside diameter of the pipe is approximately 76 mm = 0.076 m; its effective cross-sectional area (A_p) is:

$$A_p = \pi d^2/4 = 3.14 \times (0.076)^2/4 = 4.53 \times 10^{-3} \text{ m}^2$$

The flow velocity (v_p) in the pipe is:

$$v_p = Q/A_p = 1.47 \times 10^{-3}/4.53 \times 10^{-3} = 0.32 \text{ m/s.}$$

ANNEX 7: CALIBRATION OF V - NOTCH WEIR

For a V - notch weir the discharge rate is calculated by the formula (Chadwick & Morfett 1992)

$$Q = 8/15 (2g)^{1/2} C \tan(\theta/2) h^{2.5} \quad (1)$$

where:

- Q (m^3/h) is the discharge rate
- θ is the angle of the notch
- h (m) is the depth of water above the vertex of the notch
- C is the coefficient of discharge which varies according to the dimensions of the weir and channel; it is evaluated experimentally in BS 3680 for various angles θ .

The above formula is derived from the Bernoulli equation and represents an ideal discharge.

According to BS 3680, the angle θ for a 60° weir can be approximated at 0.57. According to Davies and Lambert (96) '... within the accuracy of field measurements it is practical to simplify the calculations by taking an approximate constant value of $C = 0.59$ for discharge over 60° and 90° V - notch weirs...'

According to the above, formula (1) gives for $\theta = 60^\circ$

$$Q = 0.8 h^{2.5} \quad (2)$$

Table 7 shows the flow which corresponds to various heights of water above the crest. The results were obtained by using formula (2). As it can be seen from this

table, the target flow of 1.47 l/s corresponds to a height of water between 80 and 81 mm.

Table 7: Calibration of V notch weir

Height (mm)	Flow (l/s)	Filtration Rate (m/h)
10	0.01	0.005
20	0.045	0.023
30	0.120	0.06
40	0.256	0.13
50	0.447	0.23
60	0.705	0.36
70	1.037	0.53
80	1.448	0.74
81	1.493	0.76
82	1.540	0.78
83	1.587	0.80
84	1.636	0.83
85	1.685	0.85
90	1.944	0.98
100	2.529	1.29

ANNEX 8: DESIGN OF BAGS FOR POLYSTYRENE MEDIA

I. Small beads

The diameter of the tank is assumed to be 3 m. Its area (A) is:

$$* \quad A = (\pi d^2)/4 = (3.14 \times 3^2)/4 = 7.065 \text{ m}^2$$

The thickness of the oversized media layer is 0.1 m, so the volume (V_o) of the oversized beads is:

$$* \quad V_o = A \times 0.1 \text{ m} = 7.065 \text{ m}^2 \times 0.1 \text{ m} = 0.70 \text{ m}^3 = 700 \text{ l}$$

The thickness of the small media layer is 0.65 m, so the total volume (V_{sT}) of the small beads is:

$$* \quad V_{sT} = A \times 0.65 \text{ m} = 7.065 \text{ m}^2 \times 0.65 \text{ m} = 4.59 \text{ m}^3 = 4590 \text{ l}$$

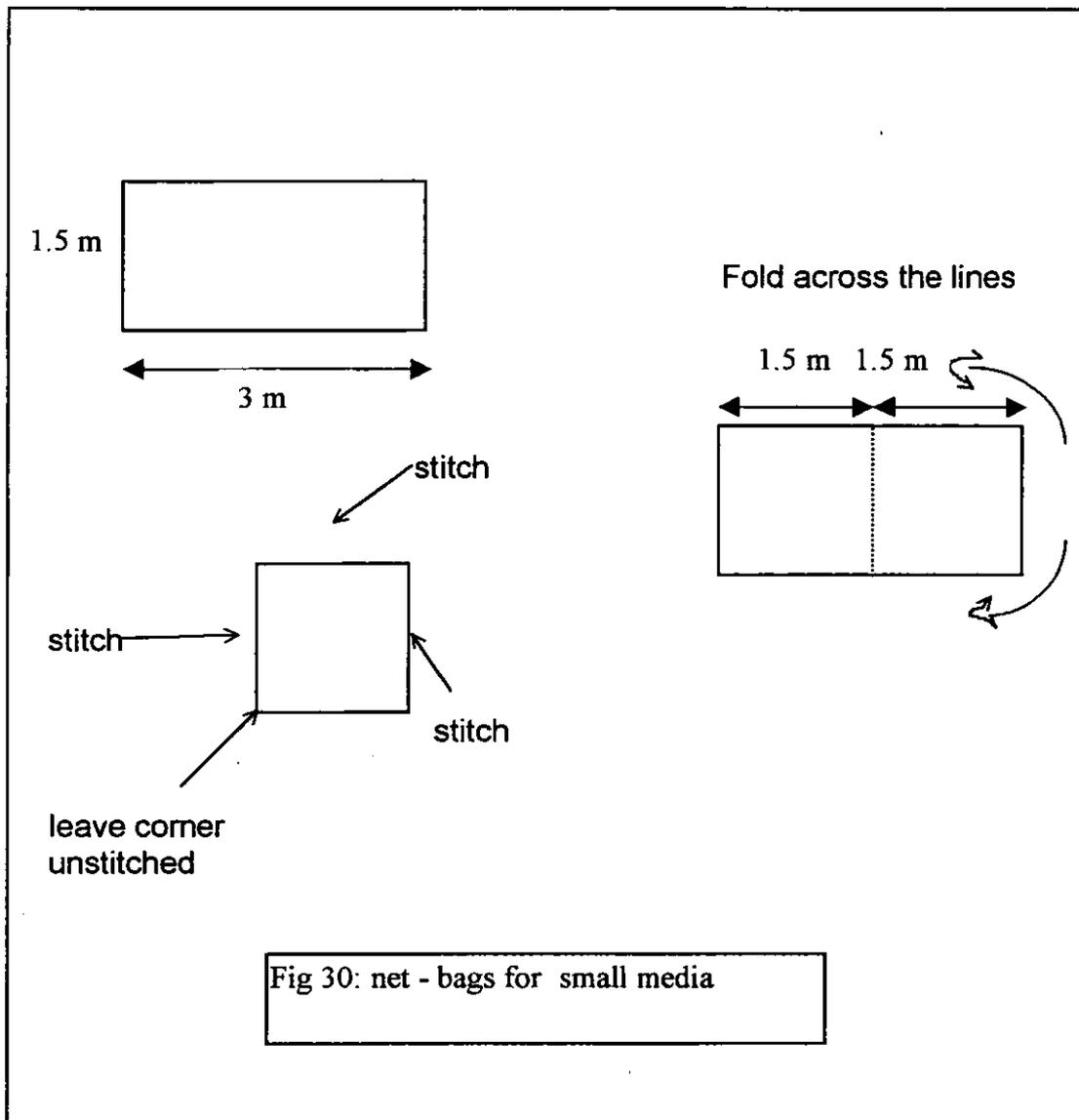
Assuming that the above layer is broken down into three layers, the volume of beads ($V_{s/i}$) in each layer becomes

$$* \quad V_{s/i} = 4.59 \text{ m}^3/3 = 1.53 \text{ m}^3 = 1530 \text{ l}$$

Assuming that each layer is further divided in 11 bags, each bag will contain:

$$* \quad V_{s/bag} = 1530 \text{ l}/11 = 140 \text{ l}$$

The dimensions of the bags are 1.5 x 1.5 m. The net manufacturer delivers the net with a 3 m width; by cutting a 1.5 length, folding the net in half and stitching along the lines, we end up with a bag of dimensions 1.5 x 1.5 m when flat; the bags are stitched with nylon cord which will not dissolve in water; the bag is filled with the beads through one opening on one of the corners. The bag fabrication is drawn schematically in the following figure:



II. Large beads

The thickness of the layer of large beads is 0.1 m. Their volume is:

$$0.1 \times 7.065 \text{ m}^2 = 0.706 \text{ m}^3, \text{ or approximately } 700 \text{ l}$$

The beads are divided in 6 bags; four large bags contain 180 l each and two small bags contain 80 l each. The dimensions of the large and small bags are 1.5 x 2 m and 1.5 x 1.5 m respectively. The bags are manufactured in the same way as described in the previous section for the small beads.

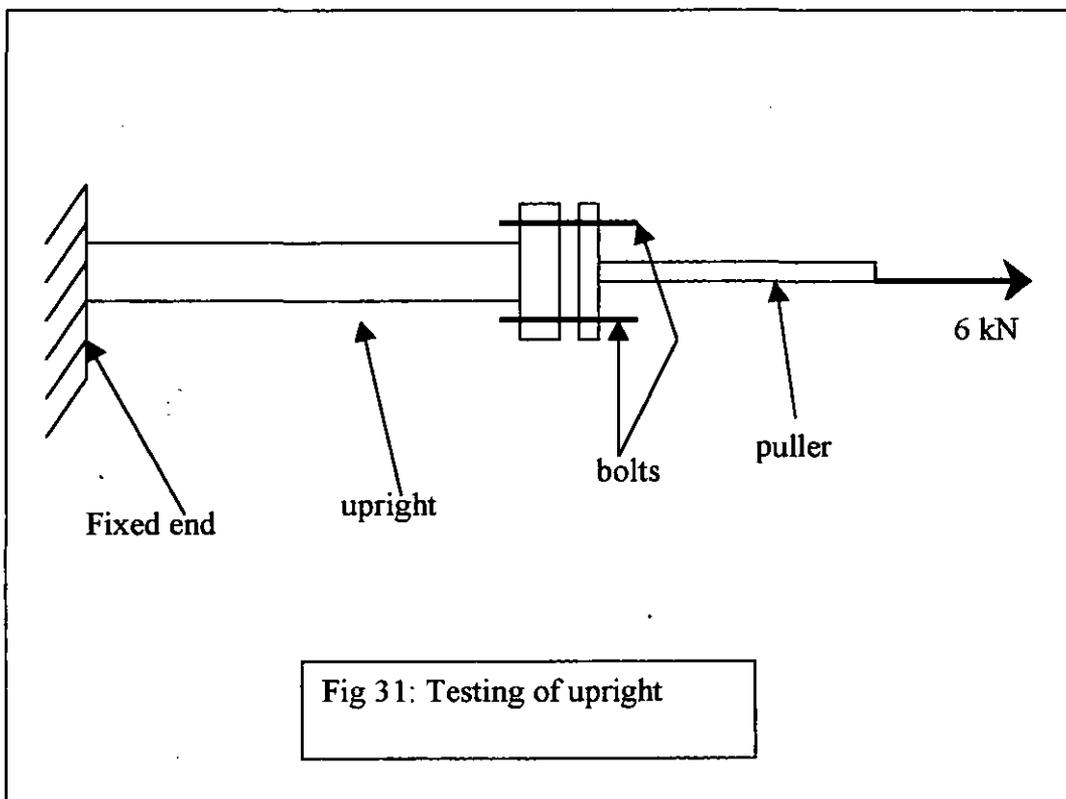
ANNEX 9: MECHANICAL TESTING OF UPRIGHTS

The design force on the uprights is expected to be 4 kN (annex 3). In order to verify whether the uprights can withstand such a tensile force, the following experiment was set up:

The bottom end of the upright was fixed; the top end was connected to a puller which applied a force of 6 kN for 24 hrs. At the end of the experiment, no failure was observed on the upright.

Since the applied force (which is greater than the design force) did not destroy the upright, it can be concluded that the upright can carry the tensile load which is transmitted by the upthrust of the beads.

The set up of the experiment is presented in fig 31.



ANNEX 10: DESIGN OF LATTICE FOR MEDIA

10.1 Introduction

The lattice is can be divided in the following components:

- the 11 - sided frame which is placed on the mesh on top of the media; it is composed of 2 concentric 'rings' which are connected to each other with a section of channel.
- 11 aluminium angles and 11 aluminium rods which are fixed to the tank's frame and keep the 11 - sided frame down

The 11 - sided frame can be seen in drawing 13.

The aluminium angles and rods can be seen in drawings 14 and 15 respectively.

The full force from the beads is 27.8 kN (Annex 2). With a factor of safety of 1.6, the full force becomes $27.8 \text{ kN} \times 1.6 = 44.5 \text{ kN}$

The design of the bolts and the connected parts is based on BS5950 (Structural steelwork for buildings), cl. 6.2 - 6.3. Although these standards are pertinent to steel design, it is assumed that they can also be used for aluminium by using the mechanical properties of the latter.

The formulas and constants which are applicable to the specific design of the bolts and connected parts are the following:

Bolt design

- Minimum edge distance for steel = 1.25 D, for a sawn edge

where D = diameter of the hole

- Minimum edge distance for aluminium is $1.40 D$, for a sawn edge
- Shear capacity $P_s = p_s \cdot A_s > F_s$, where

p_s = shear strength = 160 N/mm^2 for bolts grade 4.6

A_s = shear area = 84 mm^2 for M12 bolts, 115 mm^2 for M14 bolts.

F_s = applied shear

- tensile capacity $P_t = p_t \cdot A_t > F_t$, where

p_t = Tension strength = 195 N/mm^2 for bolts grade 4.6

$A_t = A_s$

F_t = applied tension

- Bearing capacity $P_{bb} = p_{bb} d t > F_b$, where

p_{bb} = bearing strength = 435 N/mm^2 , for bolts grade 4.6

d = diameter of opening

t = thickness of the ply

F_b = applied load

- Combined stresses

In combined shear and tension requires that in addition to $F_s < P_s$ and $F_t < P_t$,

$$(F_s/P_s) + (F_t/P_t) < 1.4$$

Connected parts design

- Bearing capacity, $P_{bs} = d t p_{bs} > F_b$ and $P_{bs} < 1/2 e t p_{bs}$, where

p_{bs} = bearing strength of connected parts = 460 N/mm² for steel grade 43, or 139 N/mm² for aluminium grade 6063 T6.

e = edge distance

d = diameter of opening

t = thickness of the ply

- If bending stresses arise, they are calculated from simple bending theory and are kept below the moment capacity of the connected part.

10.3 Aluminium angles and rods

The aluminium angles and rods are both connected at one end to the tank's frame with the aid of two sections of steel angle; the other end is connected to the inner and outer ring of the 11 sided frame respectively.

It is assumed that both components act as struts, i.e. the force is transmitted along their main axis; this demands that the 11 sided frame is aligned perfectly with the tank's reinforcing frame, i.e. the 'struts' are 'superimposed' on the imaginary radii connecting the 11 corners of the tank with its centre.

Since it is difficult to predict how the forces will be distributed, as an additional factor of safety it is assumed that each set of struts will support 75% of the total load, i.e. 44.5 kN x 0.75 = 33.4 kN. Consequently, the upforce on each strut will be 33.4/11 = 3 kN. The material for both the angle and the rod is 6063 T6.

Aluminium angle acting as a strut

The angle section has dimensions of 75 x 50 x 6mm.

The resolution of the forces in the at the point of contact between the angle strut and the 11 sided frame is shown in fig 32.

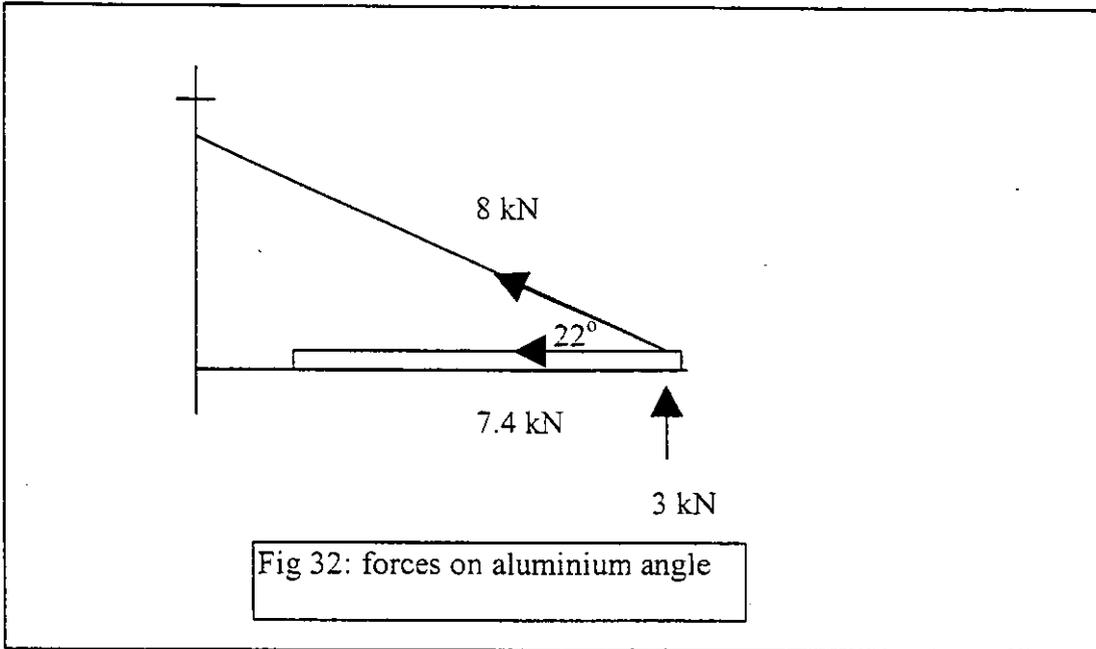


Fig 32: forces on aluminium angle

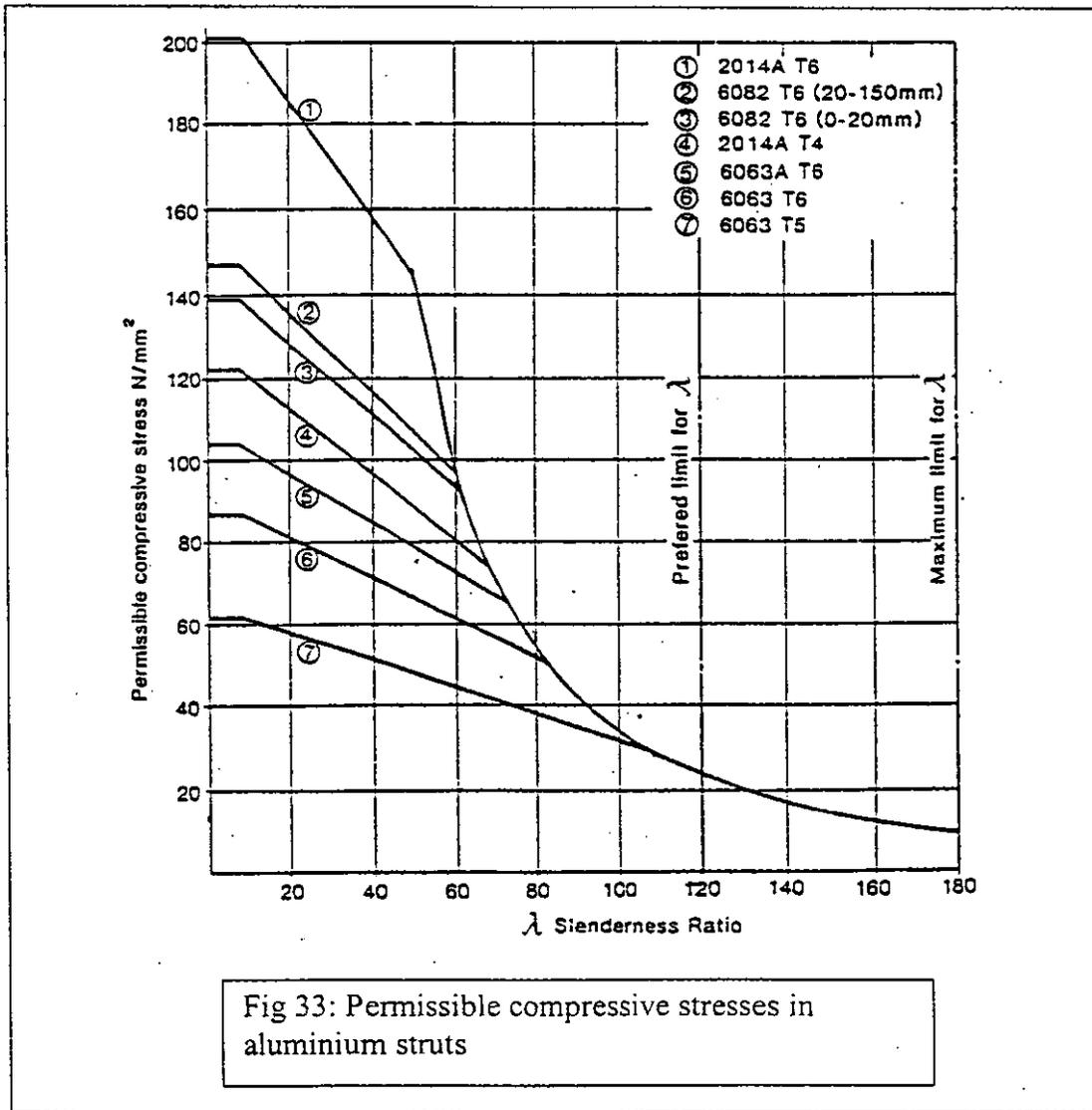


Fig 33: Permissible compressive stresses in aluminium struts

For axial loading in struts, the permissible compressive stress is obtained by inserting the appropriate slenderness ratio into the alloy/temper curves given in fig 33 (Aluminium Extrusions 1989).

The slenderness ratio can be calculated from the formula:

$$\lambda = KL/r \quad (1)$$

where λ = slenderness ratio

K = end fixity factor

L = span in mm

r = radius of gyration of sector in mm

The end conditions (effectively held in position at both ends, but not restrained in direction) correspond to an end fixity factor of 1 (Aluminium Extrusions 1989).

The radius of gyration which corresponds to the aluminium angle with dimensions 75 x 50 x 6mm is approximately 10.92 mm and the cross sectional area (A) is 774 mm² (Bowen 1966); the length L is 1164 mm.

Inserting the numbers above in (1), we get:

$$\lambda = 106.5$$

That value of λ corresponds to a permissible compressive stress of about 26 N/mm² (fig 33).

The compressive stress of the angle is:

$$8 \text{ kN}/A = 8 \text{ kN}/774 \text{ mm}^2 = 10.3 \text{ N/mm}^2$$

which is below the permissible compressive stress of 26 N/mm².

Aluminium rod acting as a strut

The resolution of forces on the aluminium rod can be seen in fig 34.

The moment of inertia (I) of a circular section is

$$I = \pi R^4/4 \quad (2),$$

where R is the radius of the circle.

The radius of gyration can be calculated from:

$$r = (I/A)^{1/2} \quad (3)$$

Combining (3) and (2), we get:

$$r = R/2$$

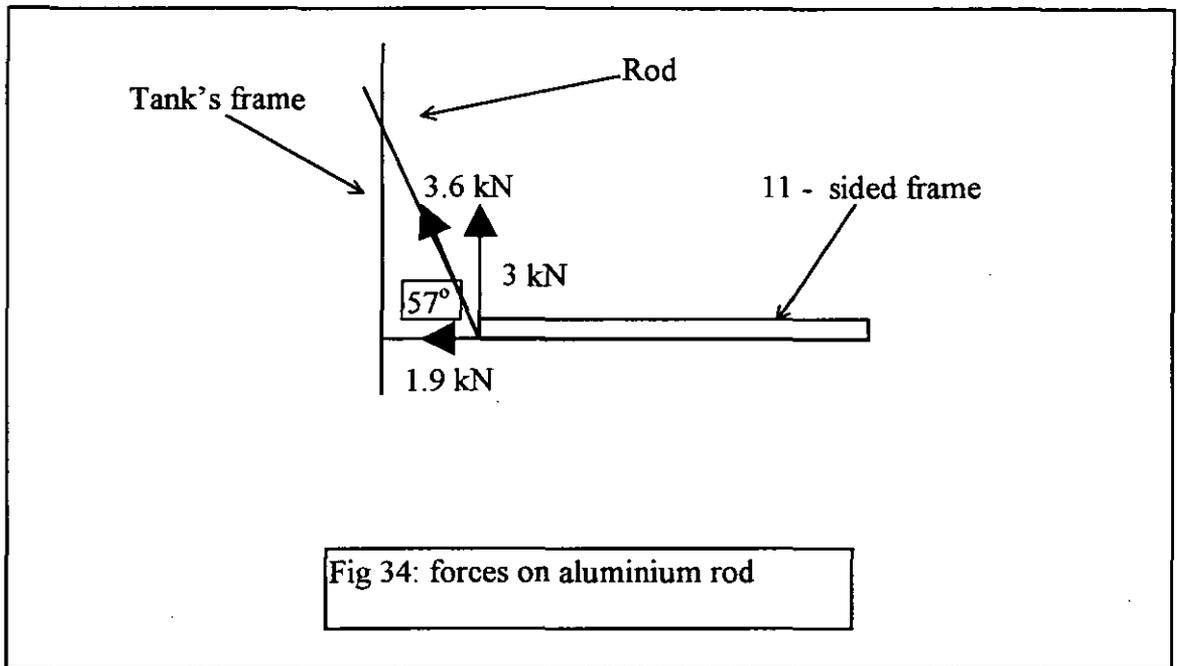
Since the radius of the aluminium rod is 9 mm, $r = 9 \text{ mm}/2 = 4.5 \text{ mm}$

The length of the rod (L) is 510 mm; λ thus becomes

$$\lambda = L/r = 510 \text{ mm}/4.5 \text{ mm} = 113$$

From fig 33, we can see that the above value of λ corresponds to a permissible compressive stress of about 25 N/mm^2 .

The compressive stress is $3.6 \text{ kN/A} = 3.6/254 \text{ mm}^2 = 14.2 \text{ N/mm}^2$, which is below the permissible stress.

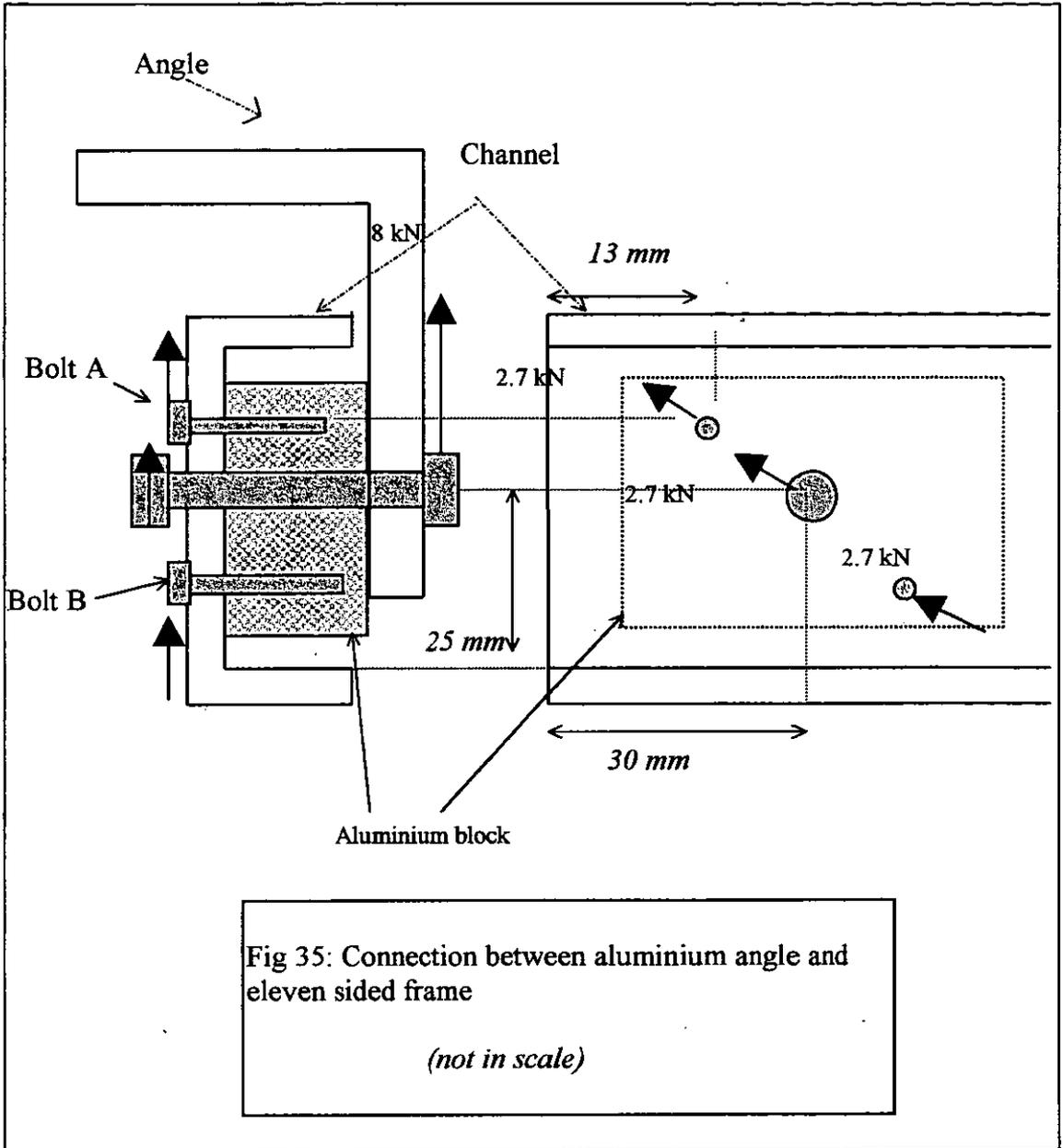


Connections at end of aluminium angle

The channel is reinforced with the addition of a solid aluminium block; the block is fixed on the inside of the channel with two M6 coated steel bolts. The aluminium angle is fixed to the block and the channel with a M14 coated steel bolt.

The upforce from the beads is thus transmitted through the 11 sided frame to the aluminium angle.

The forces at the connection between the aluminium angle and the 11 - sided frame can be seen at fig 35.



I. Connection of angle (strut) to channel

Design forces

- on M14 bolt: 8 kN (at point of contact w/ angle)
- on M6 bolts: $8/3 = 2.7$ kN (at point of contact with channel)

Bolt checks

M14 bolt:

$$P_s = p_s \times A_s = 160 \text{ N/mm}^2 \times 113 \text{ mm}^2 = 18 \text{ kN} \quad > 8 \text{ kN: shear OK}$$

$$P_{bb} = p_{bb} \times d \times t = 435 \text{ N/mm}^2 \times 14 \text{ mm} \times 25 \text{ mm} = 152 \text{ kN} \quad > 8 \Rightarrow \text{bearing OK}$$

- M6 bolts:

$$P_s = p_s \times A_s = 160 \text{ N/mm}^2 \times 20 \text{ mm}^2 = 3.2 \text{ kN} \quad > 2.7 \text{ kN : shear OK}$$

$$P_{bb} = p_{bb} \times d \times t = 435 \text{ N/mm}^2 \times 6 \text{ mm} \times 20 \text{ mm} = 52,2 \text{ kN} \quad > 2.7 \text{ kN} \Rightarrow \text{bearing OK}$$

Parts check

- Angle

check for shear & bearing on 14 mm opening

$$\text{Minimum edge distance} = 1.5 \times D = 1.5 \times 14 = 21 \text{ mm} \quad < 30 \text{ mm} \Rightarrow \text{shear OK}$$

$$P_{bs} = p_{bs} \cdot d \cdot t < 1/2 \cdot e \cdot t \cdot p_{bs}$$

$$p_{bs} \cdot d \cdot t = 139 \text{ N/mm}^2 \times 14 \text{ mm} \times 6 \text{ mm} = 11.7 \text{ kN} \quad 11.7 > 8 \text{ kN} \Rightarrow \text{bearing OK}$$

- Channel

check for shear & bearing on 6mm openings:

Min edge distance: $6 \times 1.5 = 9 \text{ mm}$

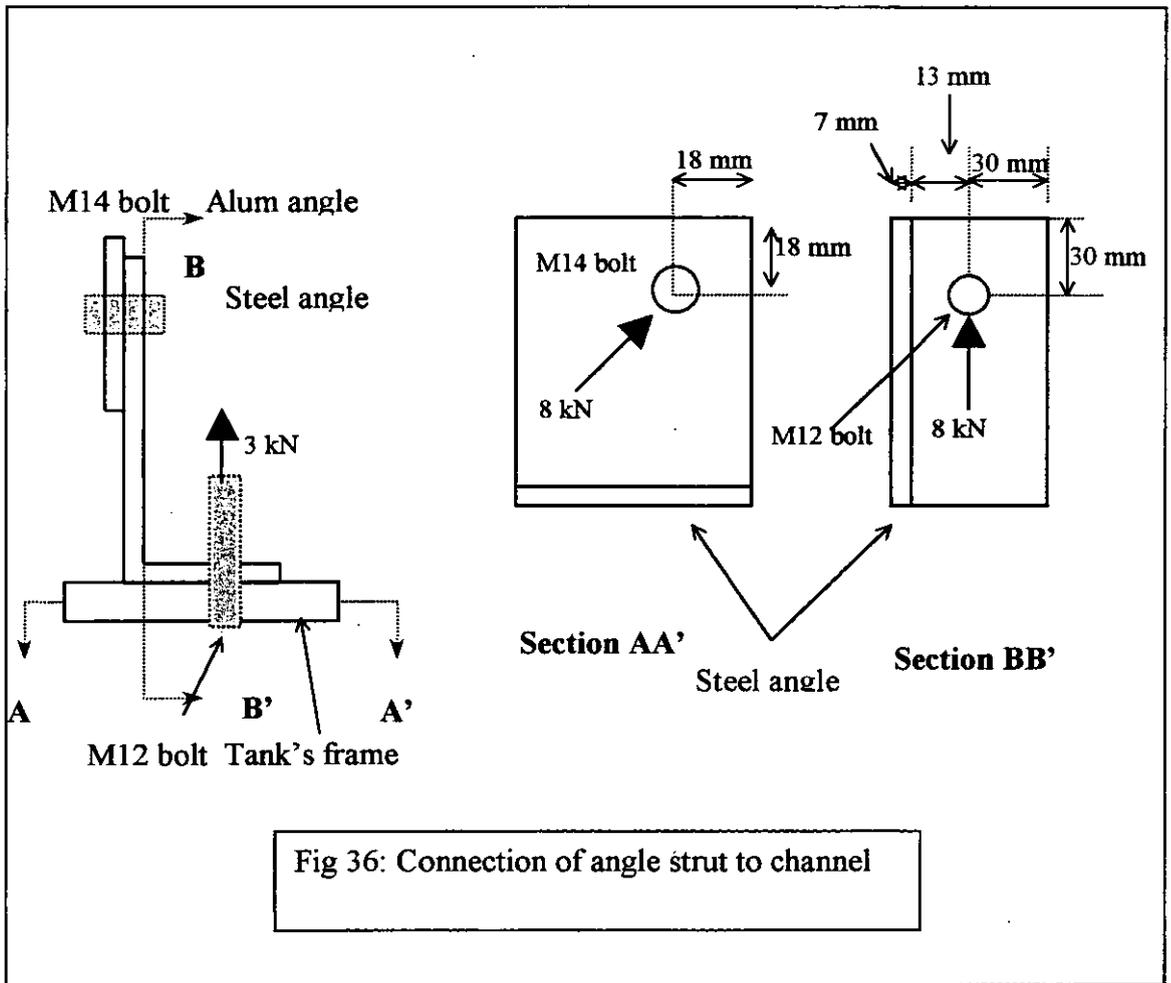
$< 13 \text{ mm} \Rightarrow$ shear OK

Bearing: $P_{bs} = 139 \text{ N/mm}^2 \times 6 \text{ mm} \times 3 \text{ mm} = 2.5 \text{ kN}$ $2.5 > 2.7 \Rightarrow$ fails on bearing

II. Connection of aluminium angle with steel angle

The aluminium angle is fixed to the steel angle with a M14 coated steel bolt. The angle iron is fixed to the tank's frame with a M12 coated steel bolt. The load from the beads is transmitted through the aluminium angle to the steel angle and then to the tanks frame. It is assumed that the connected pieces are parallel to each other and that the forces are only on the shear level.

The forces on the parts can be seen in fig 36:



Design forces

- on M14 bolt: 8 kN
- on M12 bolt: 3 kN (tension) & 7.4 kN (shear)

Bolt checks

- M14 bolt

$$P_s = p_s A_s = 160 \text{ N/mm}^2 \times 115 \text{ mm}^2 = 18.4 \text{ kN}$$

>8 kN => shear OK

$$P_{bb} = p_{bb} d t = 435 \text{ N/mm}^2 \times 14 \text{ mm} \times (7 + 6) \text{ mm} = 79 \text{ kN} \quad >8 \Rightarrow \text{bearing OK}$$

- M12 bolt

$$P_s = p_s \cdot A_s = 160 \text{ N/mm}^2 \times 84 \text{ mm}^2 = 13.44 \text{ kN} \quad > 7.4 \text{ kN} \Rightarrow \text{shear OK}$$

$$P_t = p_t \cdot A_t = 195 \text{ N/mm}^2 \times 84 \text{ mm}^2 = 16.38 \text{ kN} \quad >3 \text{ kN} \Rightarrow \text{tension OK}$$

$$F_s/P_s + F_t/P_t = (6.93/13.44) + (2.8/16.38) = 0.68 \quad < 1.4 \Rightarrow \text{combined OK}$$

$$P_{bb} = p_{bb} d t = 435 \text{ N/mm}^2 \times 12 \text{ mm} \times (7 + 10) \text{ mm} = 89 \text{ kN} \quad >7.4 \Rightarrow \text{bearing OK}$$

Parts check

- Aluminium angle

$$\text{Min edge distance} = 14 \text{ mm} \times 1.5 = 21 \text{ mm} \quad <27 \text{ mm} \Rightarrow \text{shear OK}$$

(Note: the edge distance for the aluminium angle can be seen in drawing 14)

$$P_{bs} = p_{bs} \cdot d \cdot t = 139 \text{ N/mm}^2 \times 14 \text{ mm} \times 6 \text{ mm} = 11.7 \text{ kN} \quad >8 \text{ kN} \Rightarrow \text{bearing OK}$$

- Steel bracket (at 14 mm opening)

- Min edge distance = $d \times 1.25 = 14 \text{ mm} \times 1.25 = 17.5 \text{ mm} \quad <18 \text{ mm} \Rightarrow \text{shear OK}$

$$P_{bs} = 460 \text{ N/mm}^2 \times 14 \text{ mm} \times 7 \text{ mm} = 45 \text{ kN} \quad > 8 \Rightarrow \text{bearing OK}$$

- Steel bracket (at 12 mm opening)

$$\text{Min edge distance} = d \times 1.25 = 12 \text{ mm} \times 1.25 = 15 \text{ mm} \quad < 30 \Rightarrow \text{shear OK}$$

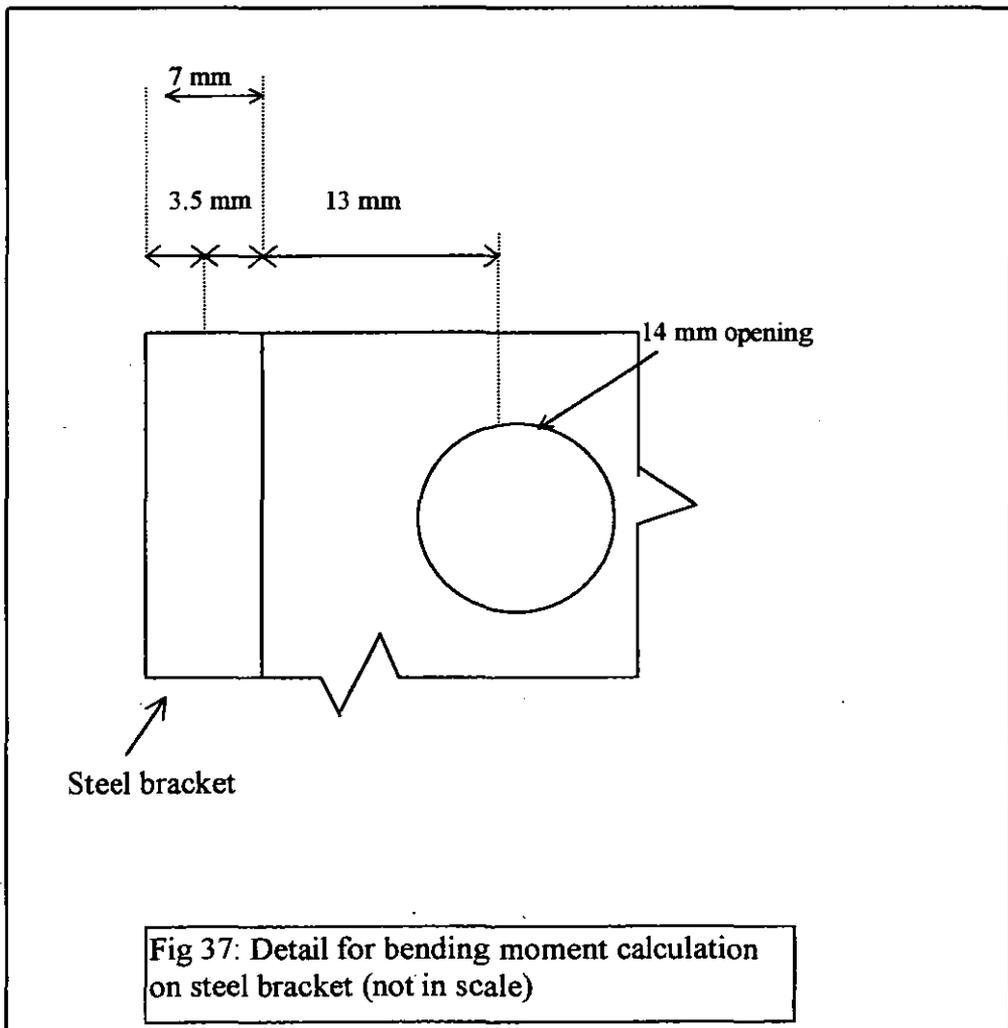
$$P_{bs} = p_{bs} \cdot d \cdot t = 460 \text{ N/mm}^2 \times 12 \text{ mm} \times 6 \text{ mm} = 33.1 \text{ kN} \quad > 7.4 \text{ kN} \Rightarrow \text{bearing OK}$$

$$P_t = A_e \cdot P_y = 6 \text{ mm} \times 100 \text{ mm} \times 275 \text{ N/mm}^2 = 165 \text{ kN} \quad > 3 \text{ kN} \Rightarrow \text{tension OK}$$

$$\text{Maximum bending moment } M_{max} = 3 \text{ kN} \times 26.5 \text{ mm} = 79.5 \text{ kN mm}$$

$$M_c = 265 \text{ N/mm}^2 \times 3.5 \text{ mm} \times 100 \text{ mm} \times 3.5 \text{ mm} = 238 \text{ kN mm (see fig 37)}$$

$$M_{max} < M_c \Rightarrow \text{bending OK}$$



III. Connection of aluminium rod with the tank's frame

The aluminium rod is fixed to the tank's frame with the aid of a section of an aluminium cylinder; a 19 mm opening is drilled through the cylinder so that the rod can pass through; the cylinder is fixed to two steel angles, which are fixed to the tank's frame.

The load from the beads is thus transmitted from the 11 - sided frame to the aluminium rod, then to the tank's frame.

Two stainless steel nuts are on the threaded rod; when the rod is under load, they touch the cylinder and keep the rod from moving.

The cylinder is machined so that two studs are extending from its two faces; each stud is fixed to one of the steel angles and effectively acts as a bolt. The effective length of the rod can be modified by moving the nuts. The original design considered using only the rods for holding the 11 sided frame down; the thickness of the media bed could thus change by modifying the rod's length.

If the rod's length changes, then the angle between the rod and the surface of the media bed would also change; that is the reason that the connections of the rod at both of its ends is such that it can rotate freely.

The forces on the cylinder and the steel angles are in fig 38 . The design checks will be made on the steel angle where the aluminium angle is fixed; if the design for that steel angle shows that it can support the combined forces of both the aluminium angle and rod, then the other angle will support the forces from just the rod.

Note: NOT TO SCALE

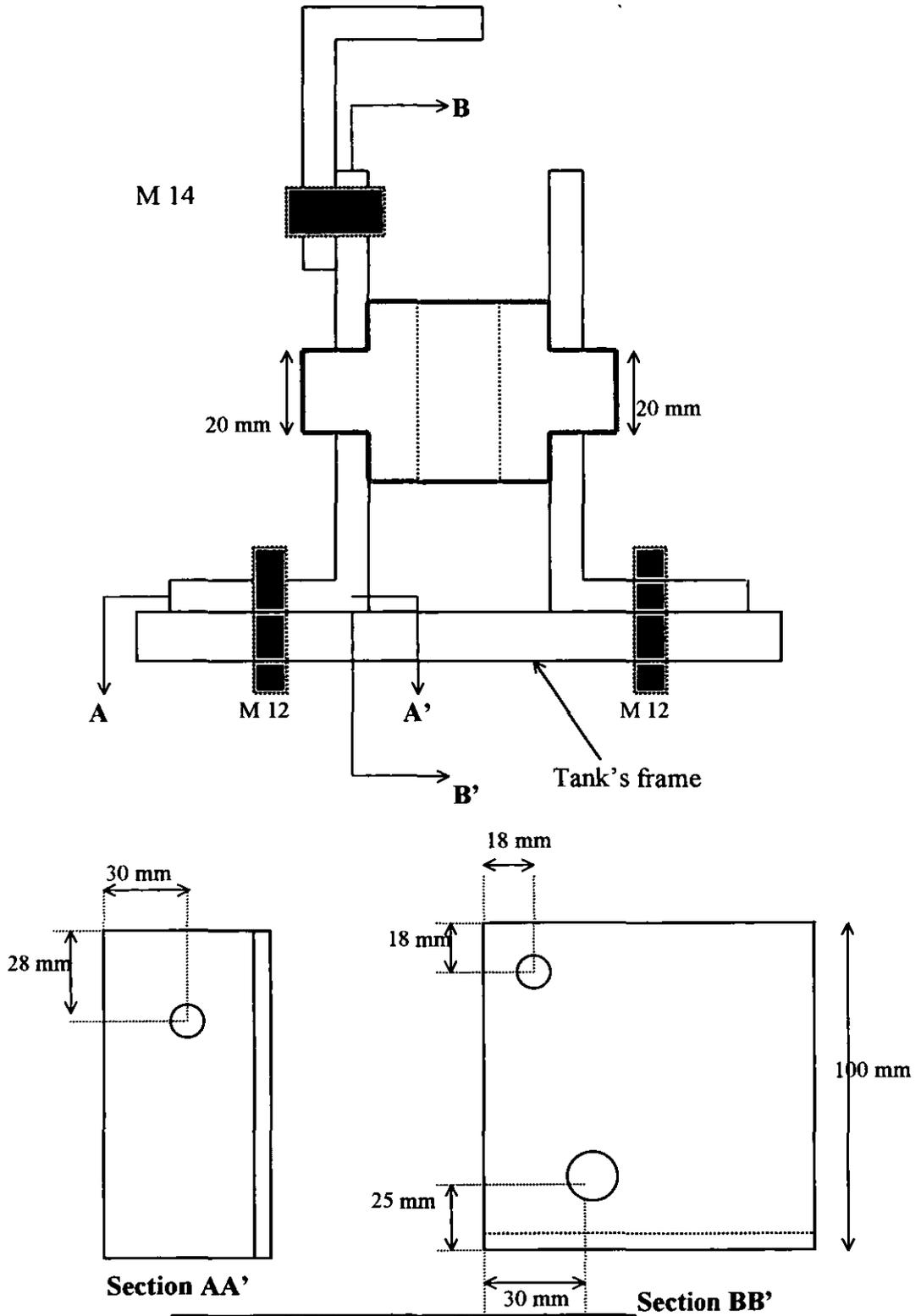


Fig 38: Forces on aluminium cylinder & connected parts

Design forces

- On M12 bolt:

Tension: 3 kN (from the rod) & 3 kN (from the angle); Total = 6 kN

Shear: 1.9 (from the rod) & 7.4 (from the angle); Total = 9.3 kN

- At 20 mm opening: $3.6/2 = 1.8$ kN

Bolts check

- M12 bolt

$$P_s = p_s A_s = 160 \text{ N/mm}^2 \times 84 \text{ mm}^2 = 13.4 \text{ kN} \quad > 9.3 \text{ kN} \Rightarrow \text{shear OK}$$

$$P_t = p_t A_t = 195 \text{ N/mm}^2 \times 84 \text{ mm}^2 = 16.4 \text{ kN} \quad > 6 \text{ kN} \Rightarrow \text{tension OK}$$

$$\text{Combined: } (F_s/P_s) + (F_t/P_t) = (8.75/13.4) + (5.6/16.4) = 0.99 < 1.4 \Rightarrow \text{combined OK}$$

$$P_{bb} = p_{bb} d t = 435 \text{ N/mm}^2 \times 12 \text{ mm} \times (7 + 10) \text{ mm} = 89 \text{ kN} > 9.3 \text{ kN} \Rightarrow \text{bear. OK}$$

Parts check

- Steel angle (at 20 mm opening)

$$\text{Min edge distance} = 1.25 \times d = 1.25 \times 20 \text{ mm} = 25 \text{ mm} \quad = 25 \text{ mm} \Rightarrow \text{Shear OK}$$

$$P_{bs} = p_{bs} d t = 460 \text{ N/mm}^2 \times 20 \text{ mm} \times 7 \text{ mm} = 64.4 \text{ kN} \quad > 1.8 \text{ kN} \Rightarrow \text{bearing OK}$$

- Steel angle (at 12 mm opening)

$$\text{Min edge distance} = 1.25 d = 1.25 \times 12 = 15 \text{ mm} \quad < 30 \text{ mm} \Rightarrow \text{shear OK}$$

$$P_{bs} = p_{bs} d t = 460 \text{ N/mm}^2 \times 12 \text{ mm} \times 7 \text{ mm} = 38.6 \text{ kN} \quad > 9.3 \text{ kN} \Rightarrow \text{bearing OK}$$

$$\text{Maximum bending moment } M_{\max} = 6 \text{ kN} \times 20 \text{ mm} = 120 \text{ kN mm}$$

$$M_c = 265 \text{ N/mm}^2 \times 3.5 \text{ mm} \times 100 \text{ mm} \times 3.5 = 324.6 \text{ kN mm}$$

$$M_{\max} < M_c \Rightarrow \text{bending OK}$$

ANNEX 11 : WEIGHTS OF INDIVIDUAL COMPONENTS

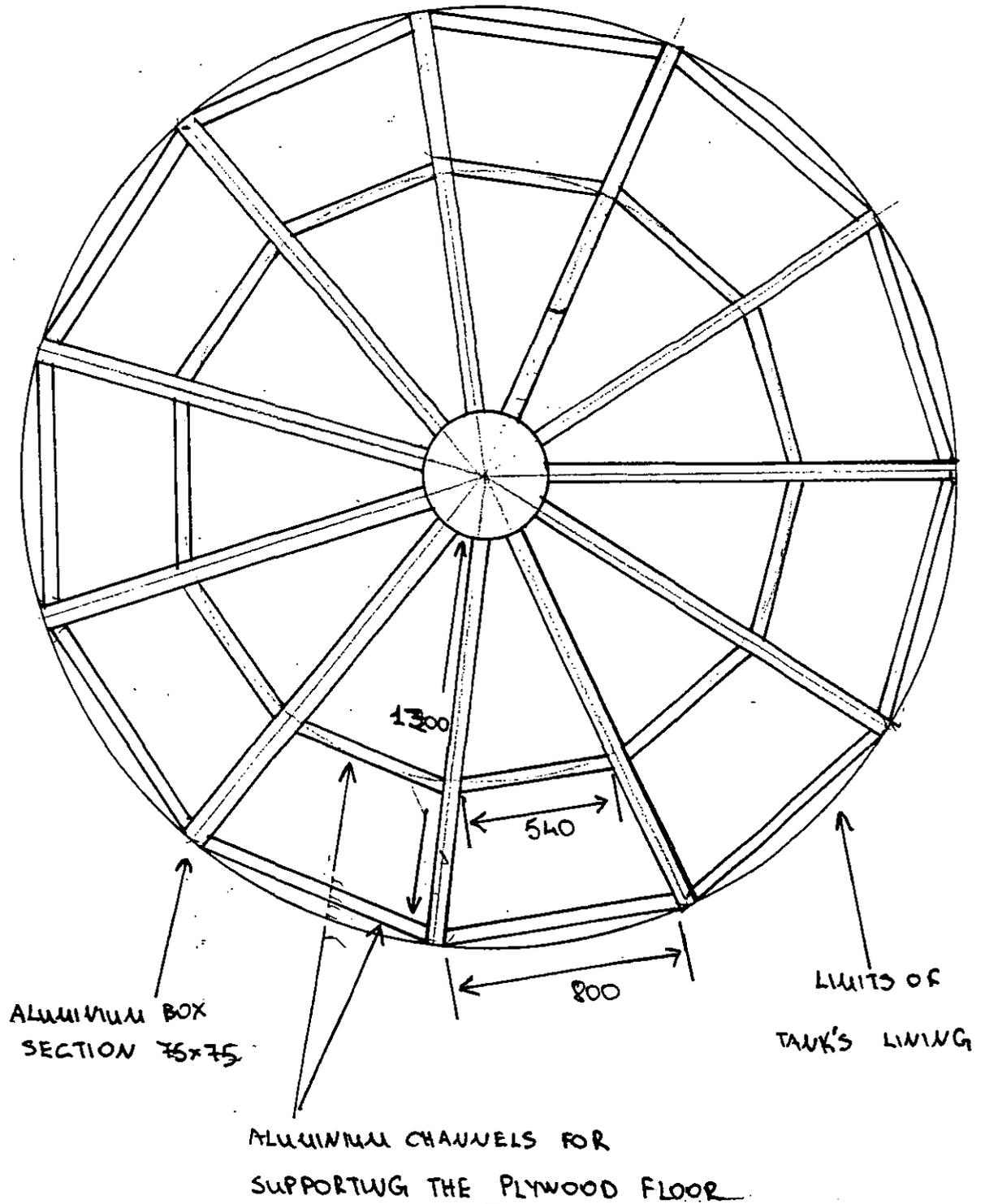
	ITEM	QUANTITY	WEIGHT (individual)	WEIGHT (total)
Water tank	lining	1		26.0
	cover	1		8.0
	uprights	11	5.0	55.0
	round tubes	33	1.12	37.0
	bolts & nuts	various		4.6
			SUB TOTAL	130.6
Base	marine	11	4.46	49.1
	marine	various		50
	alum. square	11	3.3	36.3
	L piece / short	7	2.06	14.4
	L piece / long	4	2.54	10.2
	centre piece / top	1	4.2	4.2
	centre piece bottom	1	3.4	3.4
	bolts & nuts	various		1.0
	alum. channel long	11	1.12	12.3
	alum. channel short	11	0.75	8.25
Flow	PVC box & valve	1	SUB TOTAL	9.25
	metal frame for box	1	10.1	10.1
	pipe & fittings	various		2.6
			SUB TOTAL	21.95
Drainage	pipes & fittings	various		16.0
	flanges & fittings	3	3.1	9.3
	75 mm ball valves	3	4.2	12.6
	75 mm flexible	3	10.0	30.0
	mesh	1	22.7	22.7
	supports for mesh	20	0.8	16.0
			SUB TOTAL	91.6
Collection	pipe	1		4.2
	flange & fittings	1		4.2
	50 mm flexible pipe	1		5.2
			SUB TOTAL	13.6
Lattice	mesh	1	22.7	22.7
	alum. channel	11	2.5	27.5
	alum. rod	11	0.9	9.9
	element (11 - sided	11	1.75	19.25
	steel brackets / long	11	0.73	8.03
	steel brackets /	11	0.4	4.4
	bolts & nuts	various		2.6
			SUB TOTAL	94.38
Media	Net bags	39	0.27	10.5
	beads			189.45
			SUB TOTAL	199.95
Packaging	Box and palletes	2	40	80
			TOTAL FOR THE UNIT	821.23

DRAWING 1

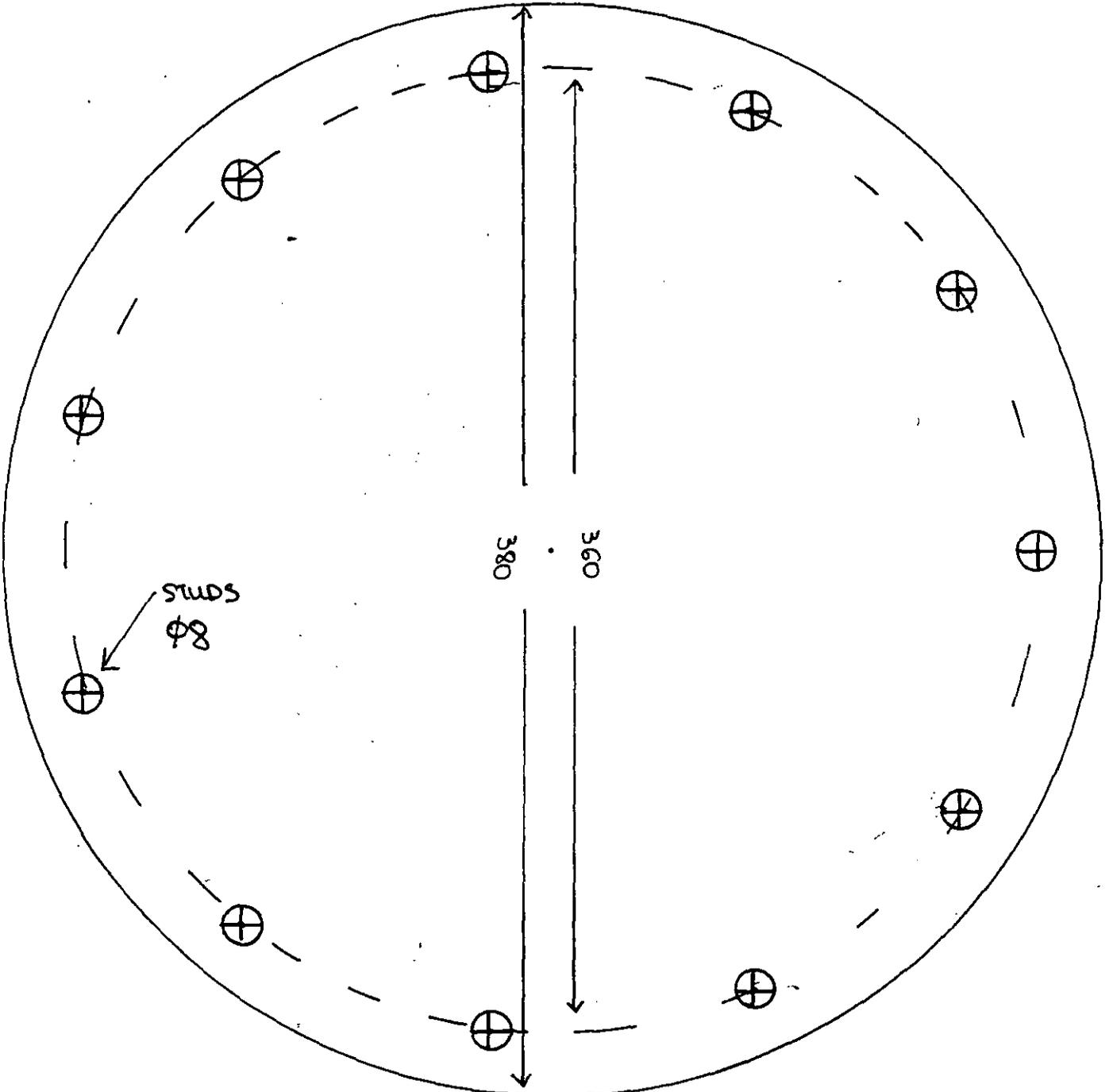
ALUMINIUM FRAME FOR BASE

SCALE: 1/20

ALL DIMENSIONS IN MM



ELEVATION (NOT W SCALE)

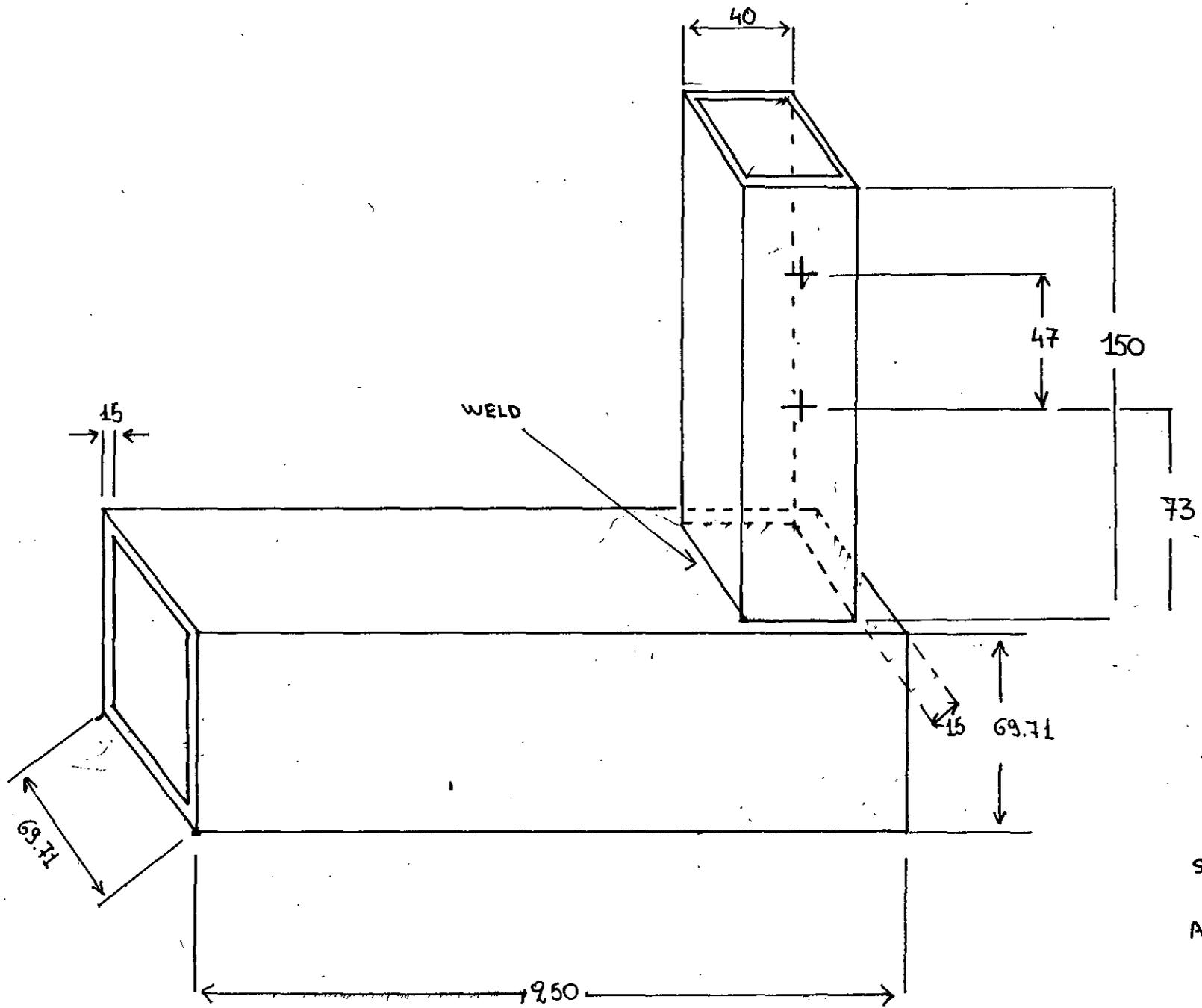


DRAWING 2

ALUMINUM CENTRAL DISC (PLAN)

SCALE: 2/1

168
ALL DIMENSIONS IN mm.

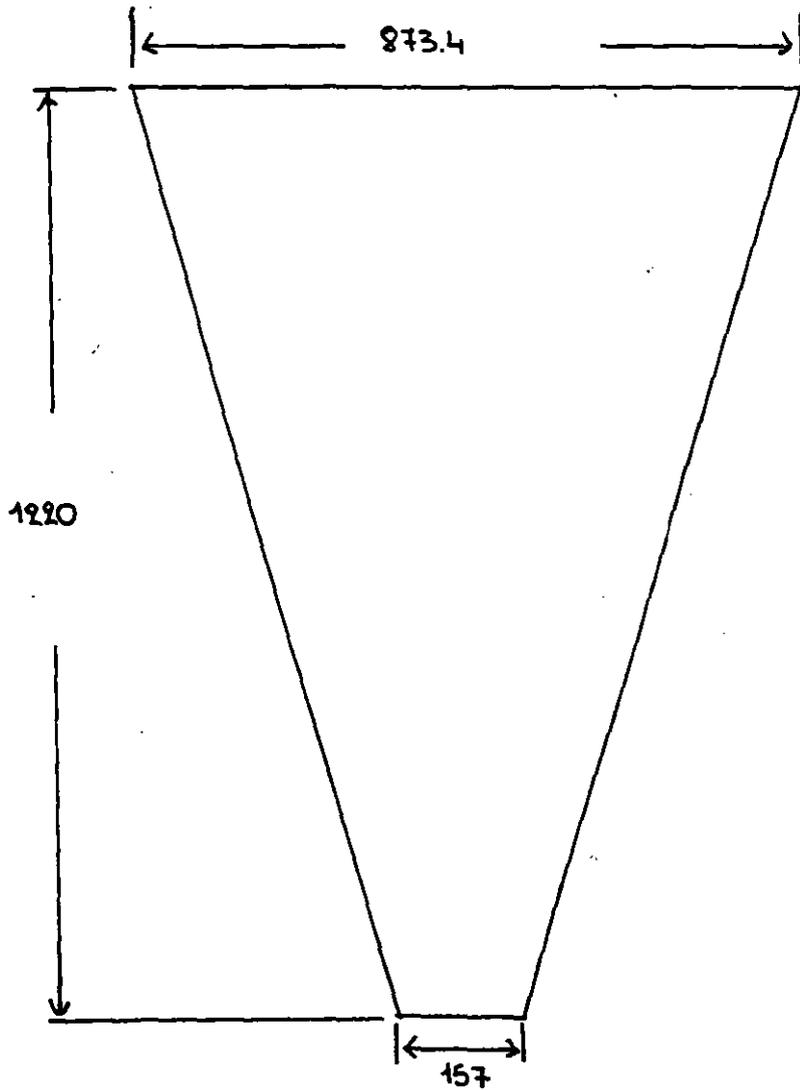


DRAWING 3

'L' PIECE

SCALE: 1/8

ALL DIMENSIONS IN MM



DRAWING 4

PLYWOOD: ELEMENT OF FLOOR

SCALE: 1/10

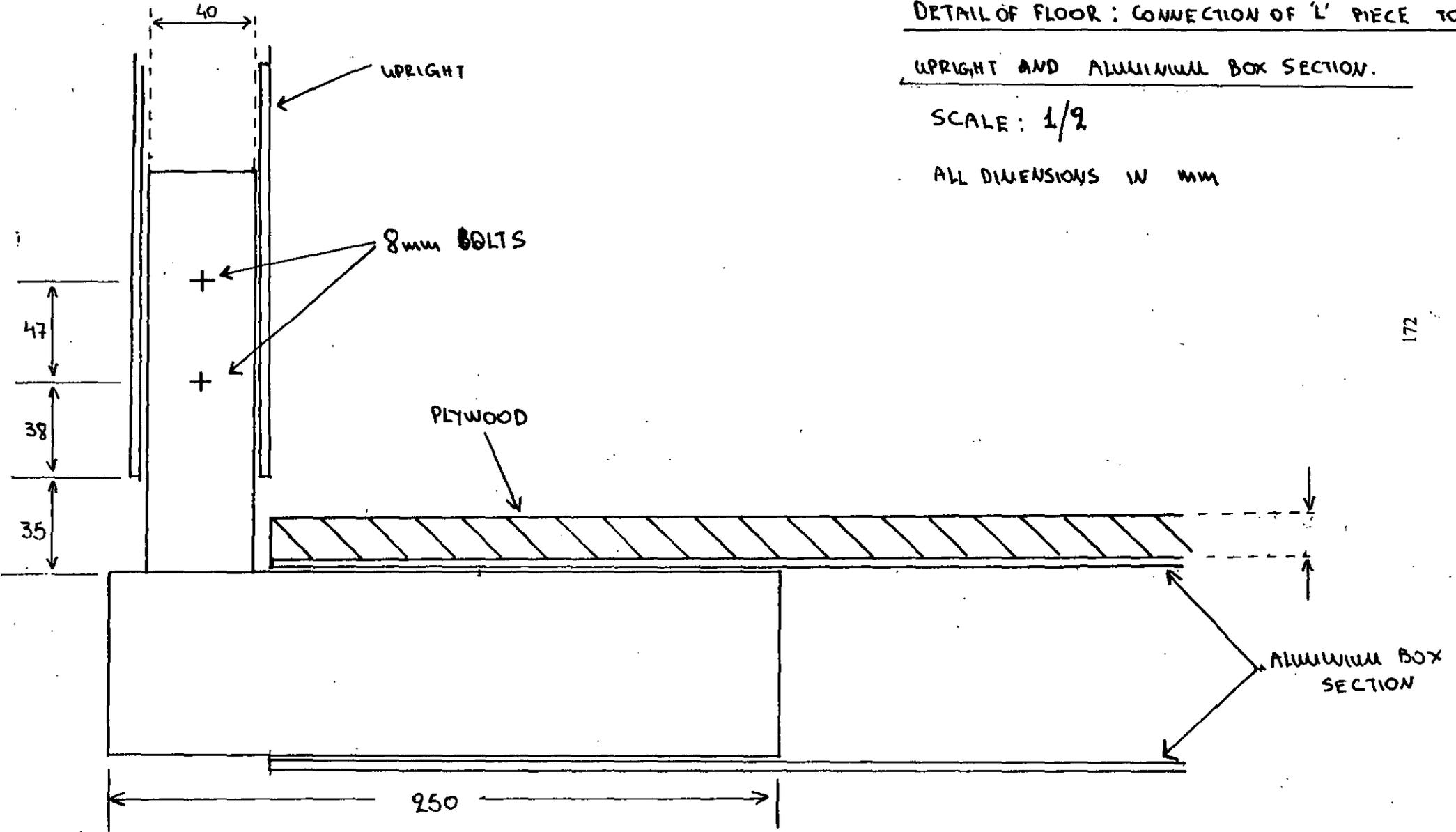
ALL DIMENSIONS IN mm

DRAWING 5

DETAIL OF FLOOR : CONNECTION OF 'L' PIECE TO UPRIGHT AND ALUMINUM BOX SECTION.

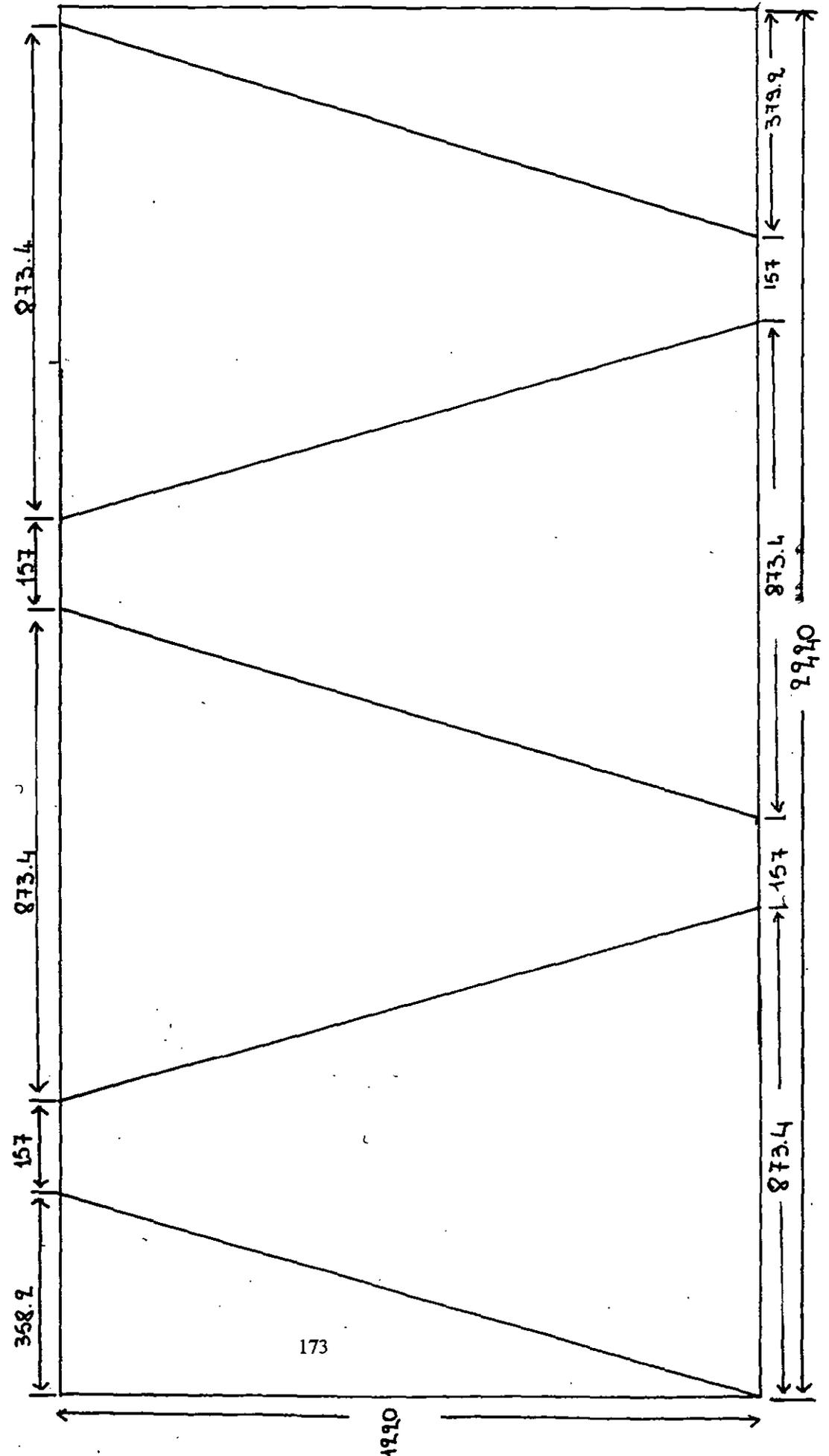
SCALE: 1/2

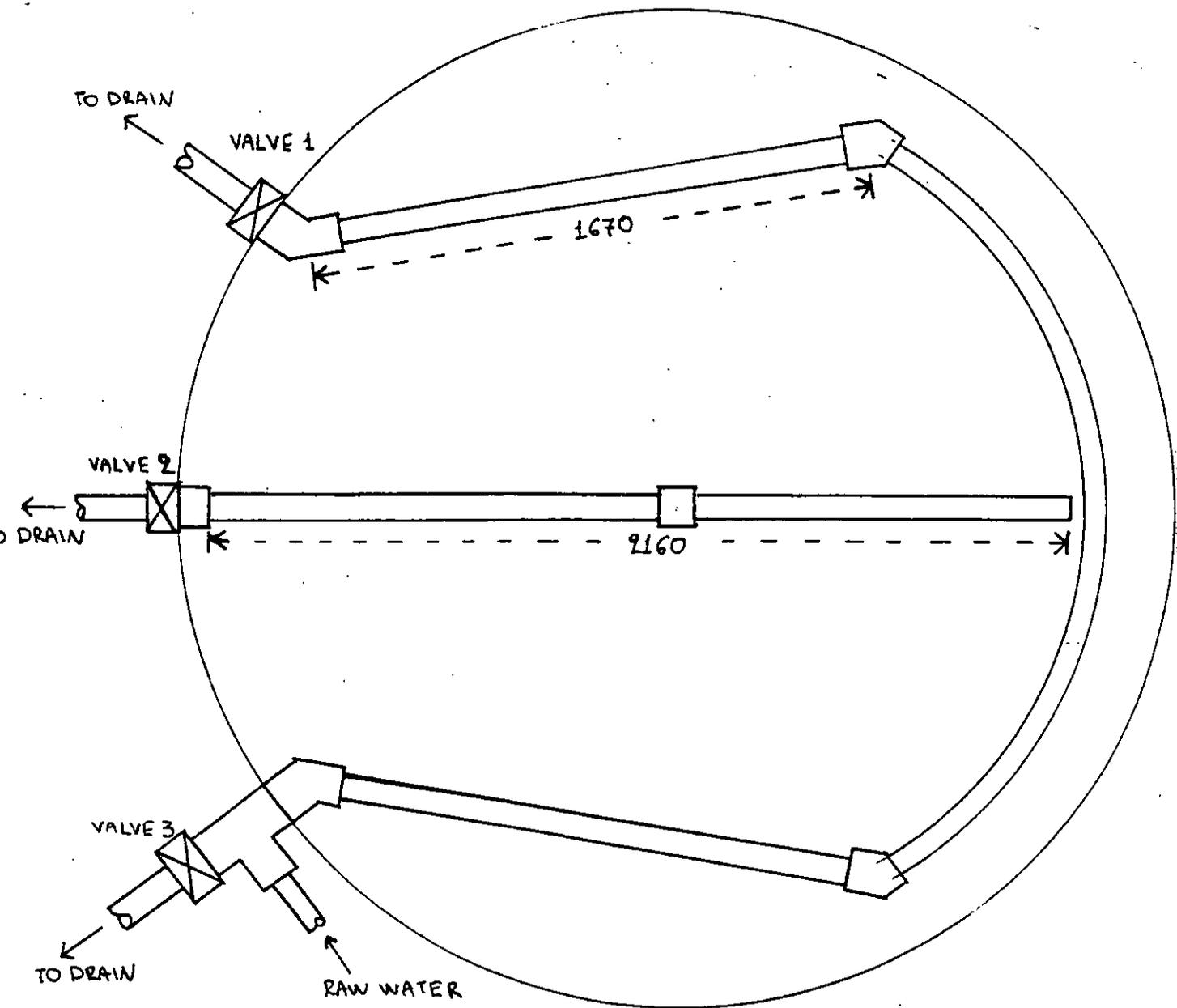
ALL DIMENSIONS IN MM



PLYWOOD BOARD: DIVISION - W 4 SECTIONS FOR THE FLOOR

SCALE: 1/10 ALL DIMENSIONS IN MM.





DURING NORMAL OPERATION: VALVE 3 OPEN
VALVES 1, 2 CLOSED

DURING DRAINAGE: ALL VALVES OPEN

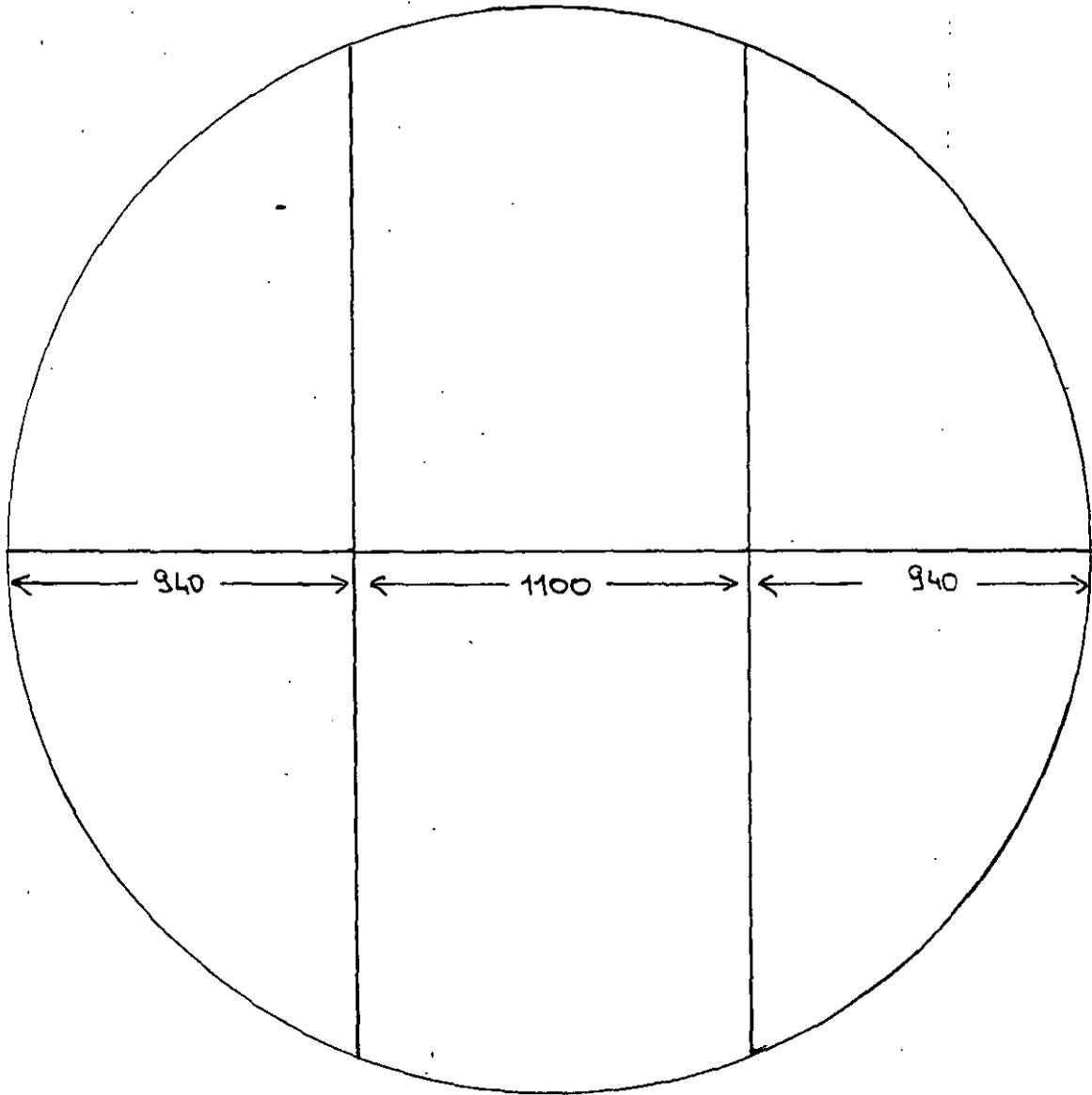
DRAWING 7

DRAINAGE

SCALE: 1/20

ALL DIMENSIONS IN MM

DIA. METER OF ALL DRAINAGE PIPES: 75mm

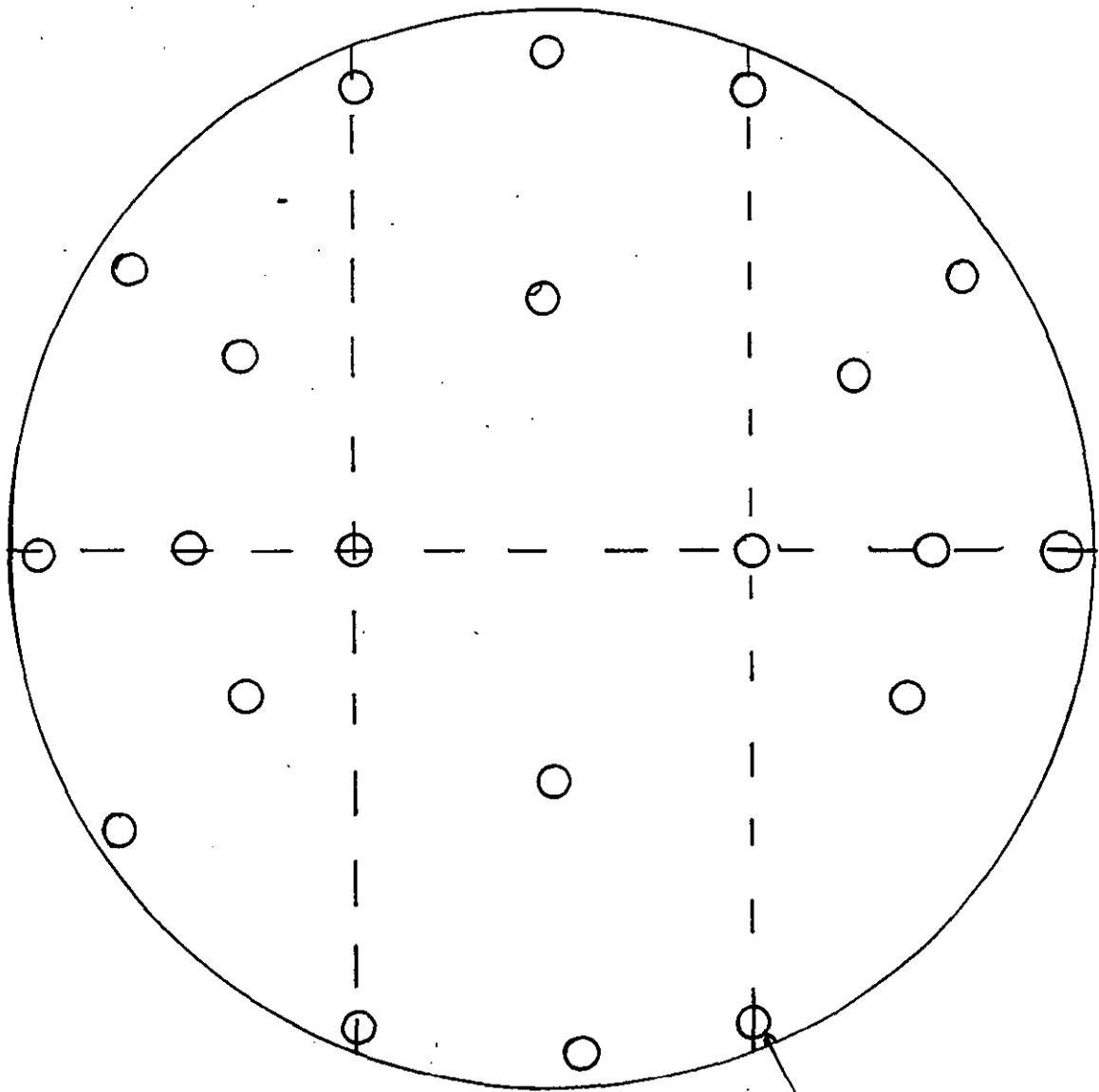


DRAWING 8

MESH FOR RAISED FLOOR

SCALE 1/20 , ALL DIMENSIONS IN MM

NOTE: THE MESH CAN FOLD ALONG THE LINES



DRAWING 9

POSITIONING OF SUPPORTS FOR RAISED FLOOR

SCALE: 1/20

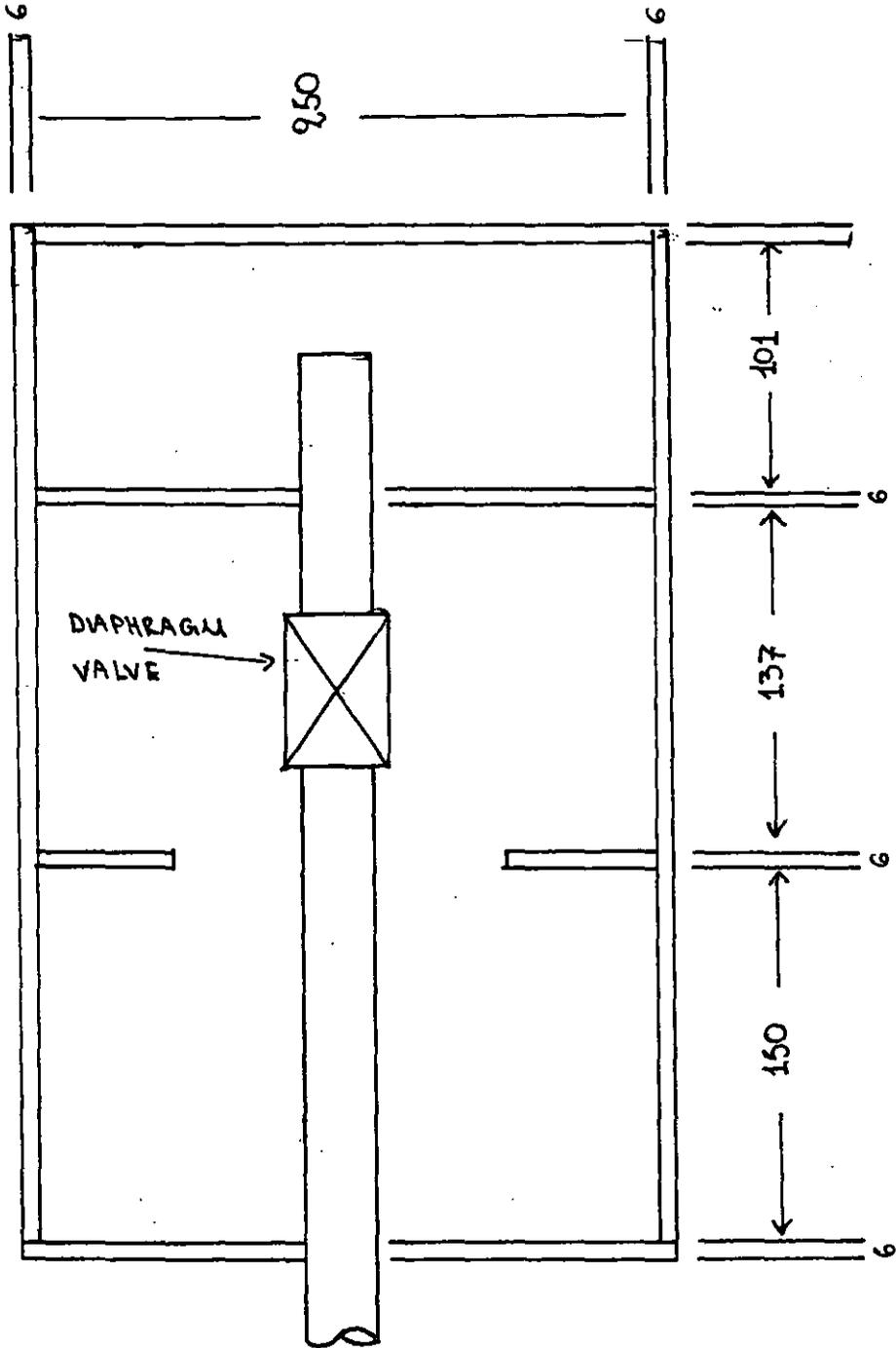
THE MESH FOLDS ALONG THE DASHED LINE

DRAWING 10

FLOW CONTROL BOX (PLAN)

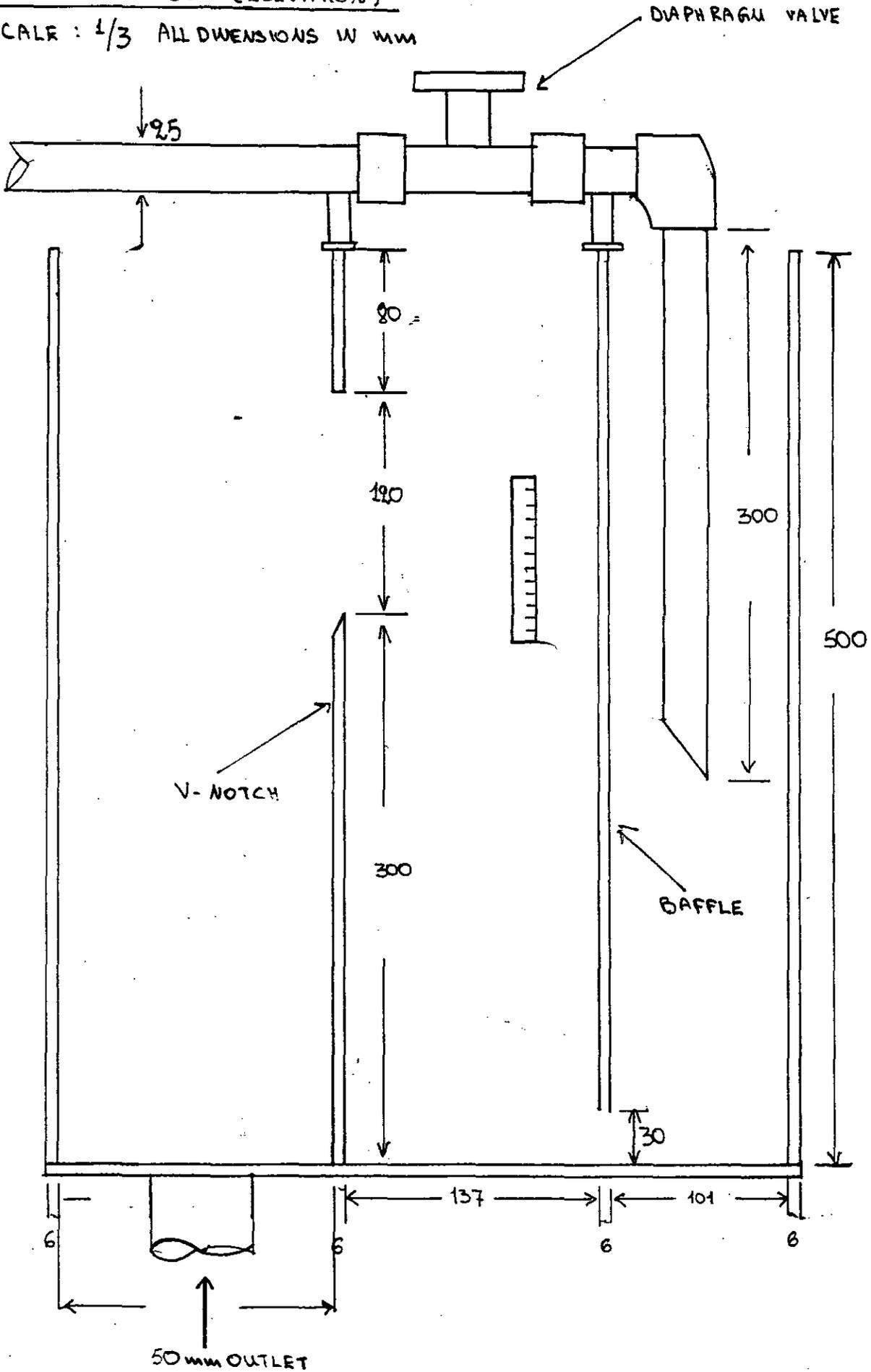
SCALE: 1/3

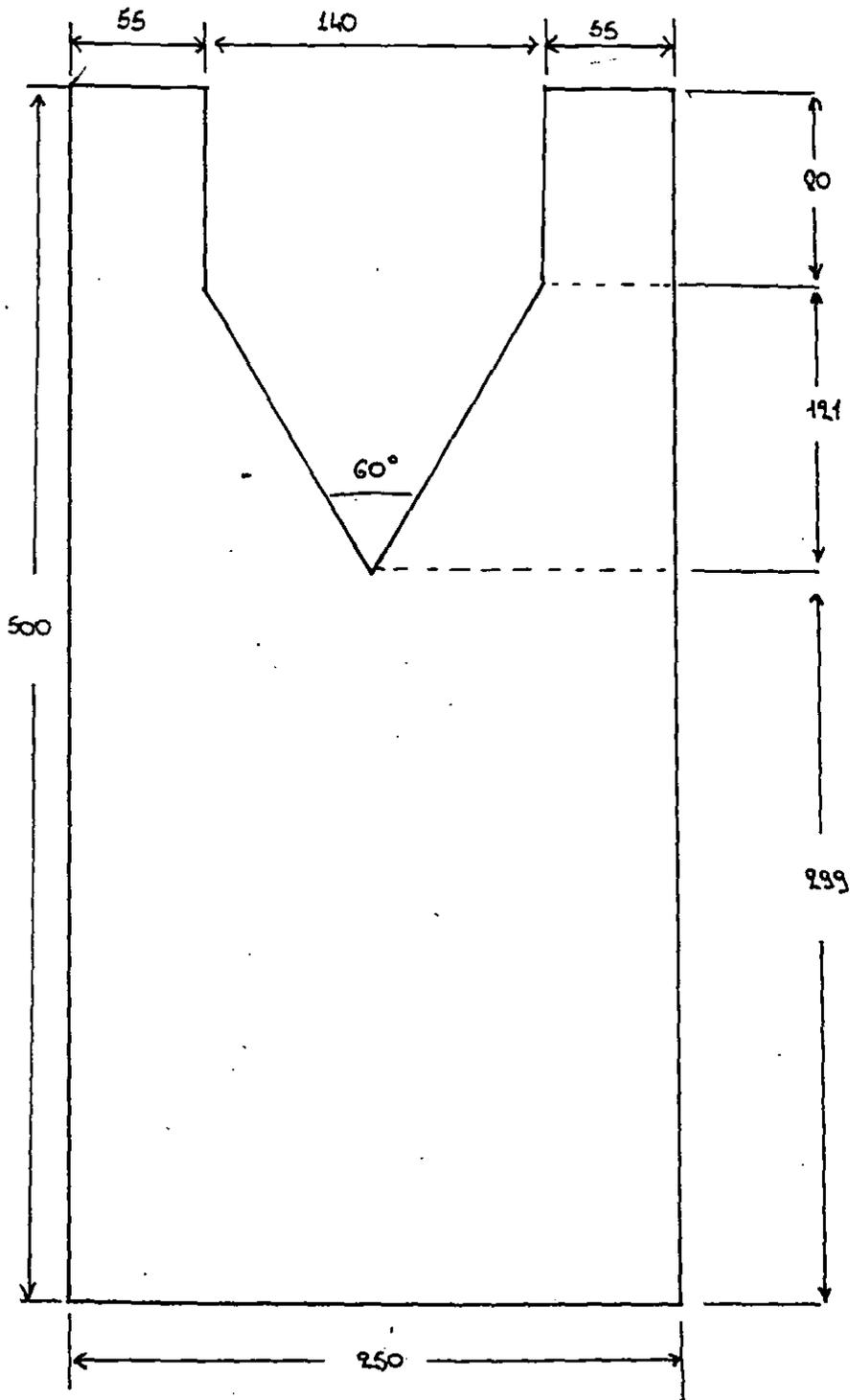
ALL DIMENSIONS IN MM.



FLOW CONTROL BOX (ELEVATION)

SCALE : 1/3 ALL DIMENSIONS IN MM



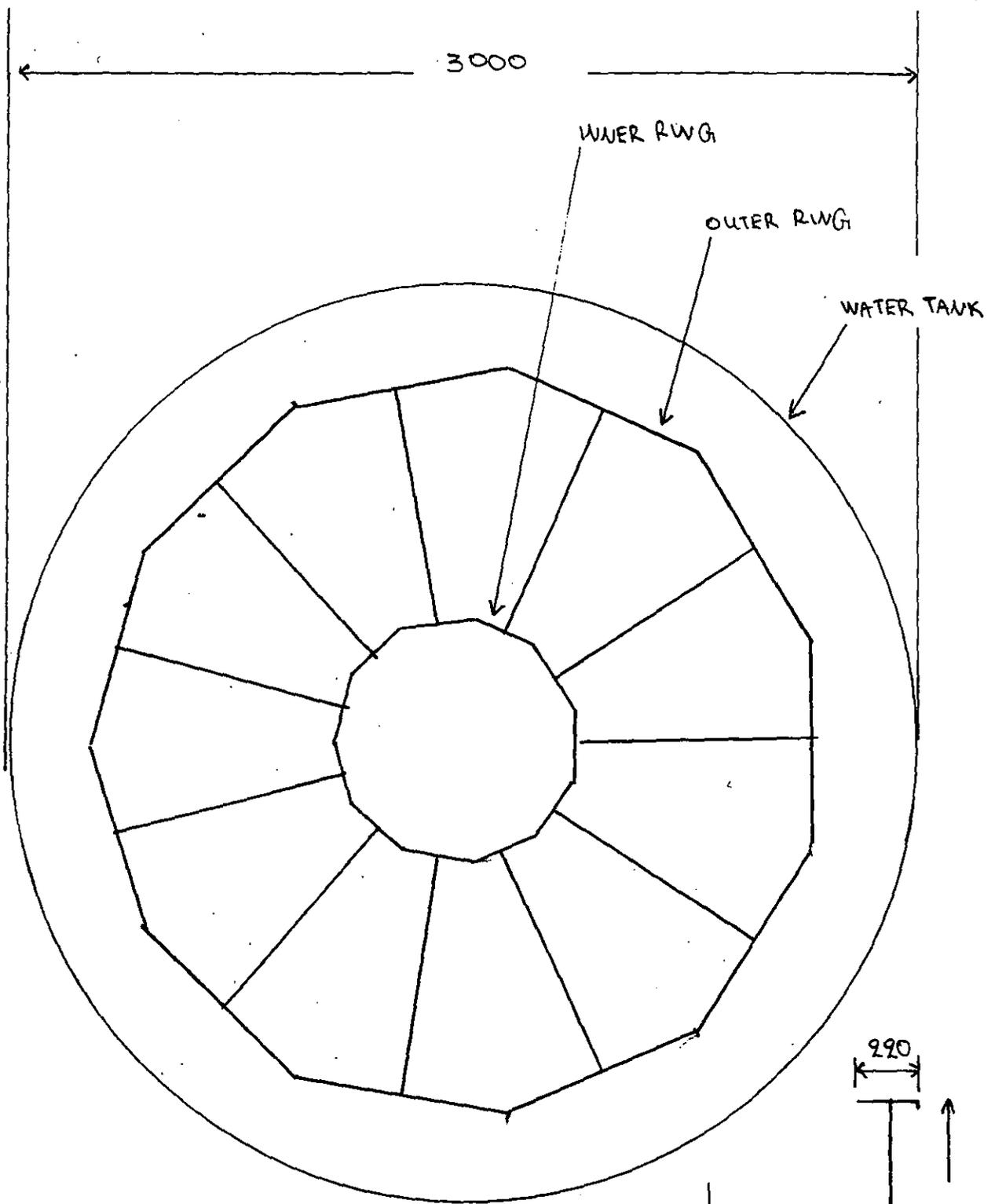


DRAWING 12

V NOTCH WEIR W FLOW CONTROL BOX

SCALE: 1/3

ALL DIMENSIONS IN MM

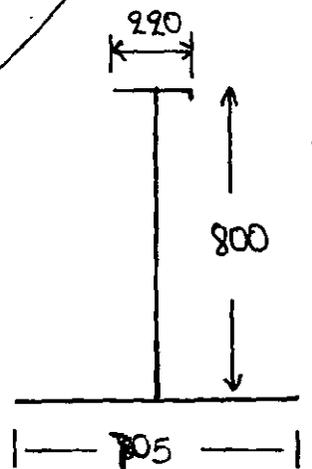


DRAWING 13

LATTICE / ELEVEN SIDED FRAME

SCALE: 1/20

ALL DIMENSIONS IN MM

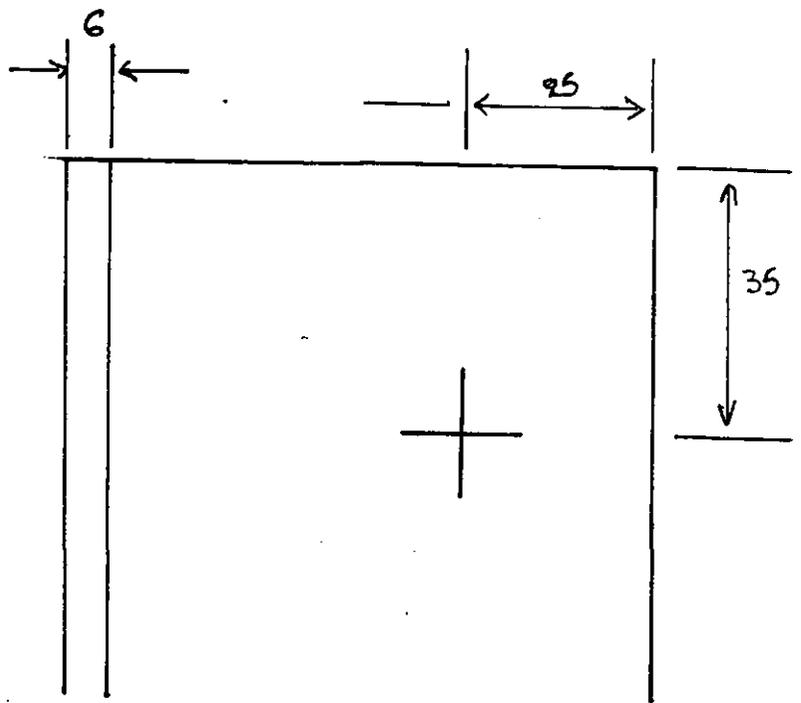


INDIVIDUAL ELEMENT

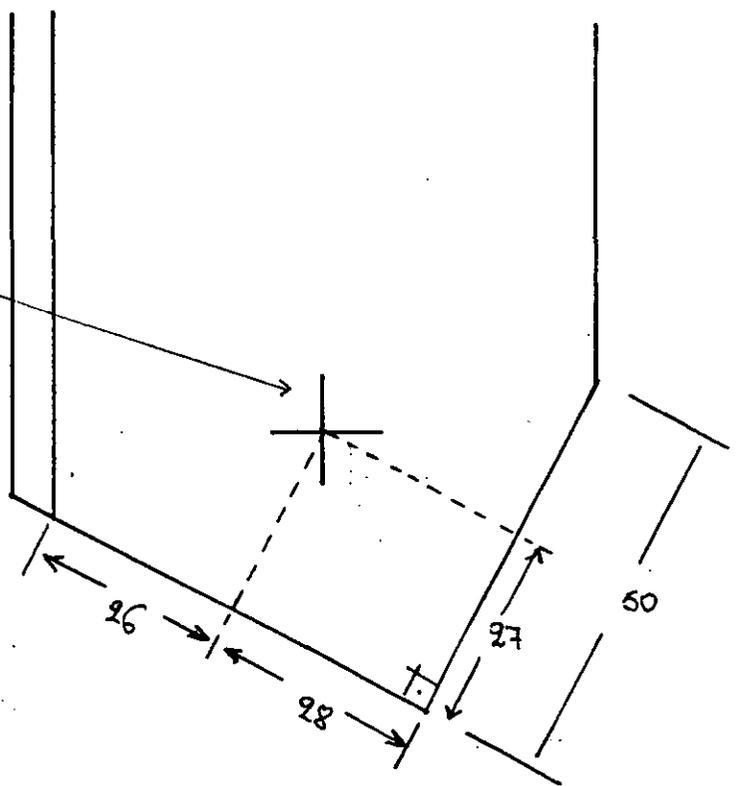
ALUMINIUM ANGLE

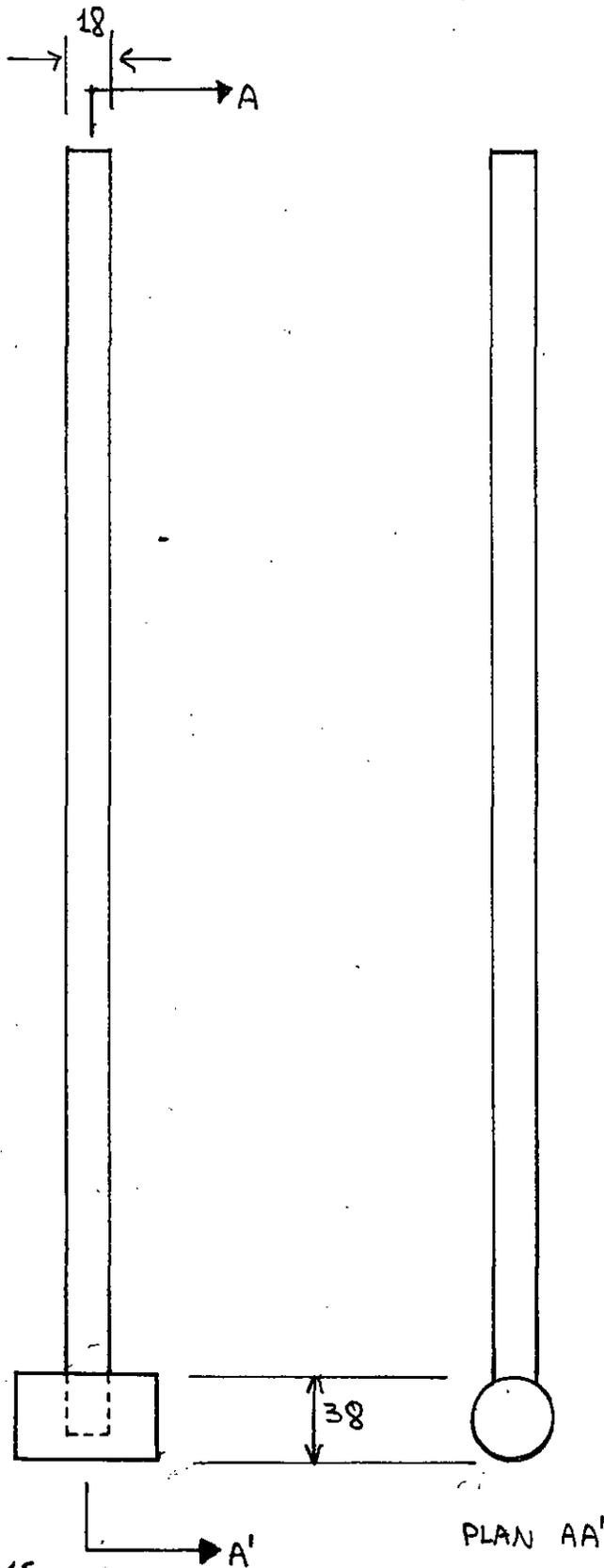
SCALE : 1/1 ALL DIMENSIONS IN MM

DRAWING 14



$\phi 16$ Bolt





DRAWWG 15

ALUMINUM ROD FOR LATTICE

SCALE 1/3

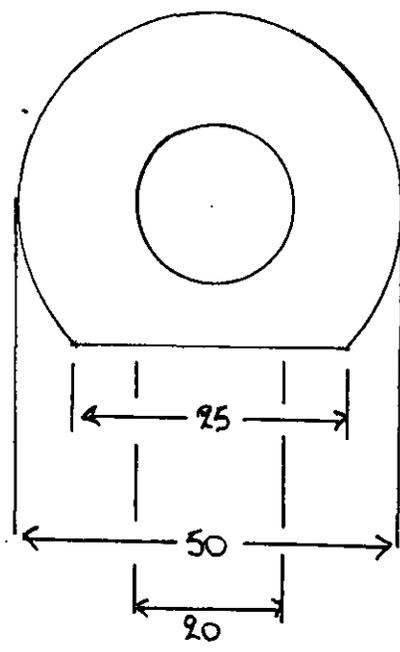
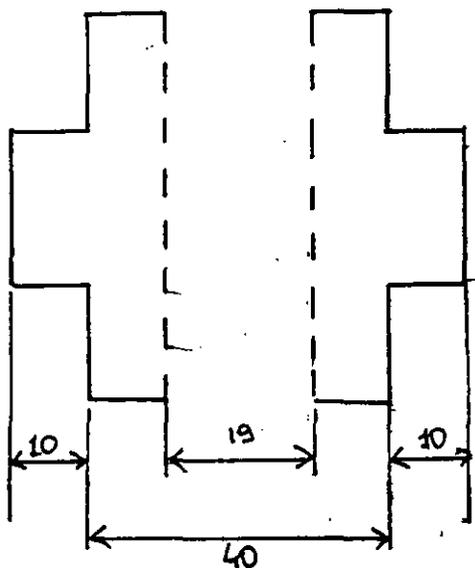
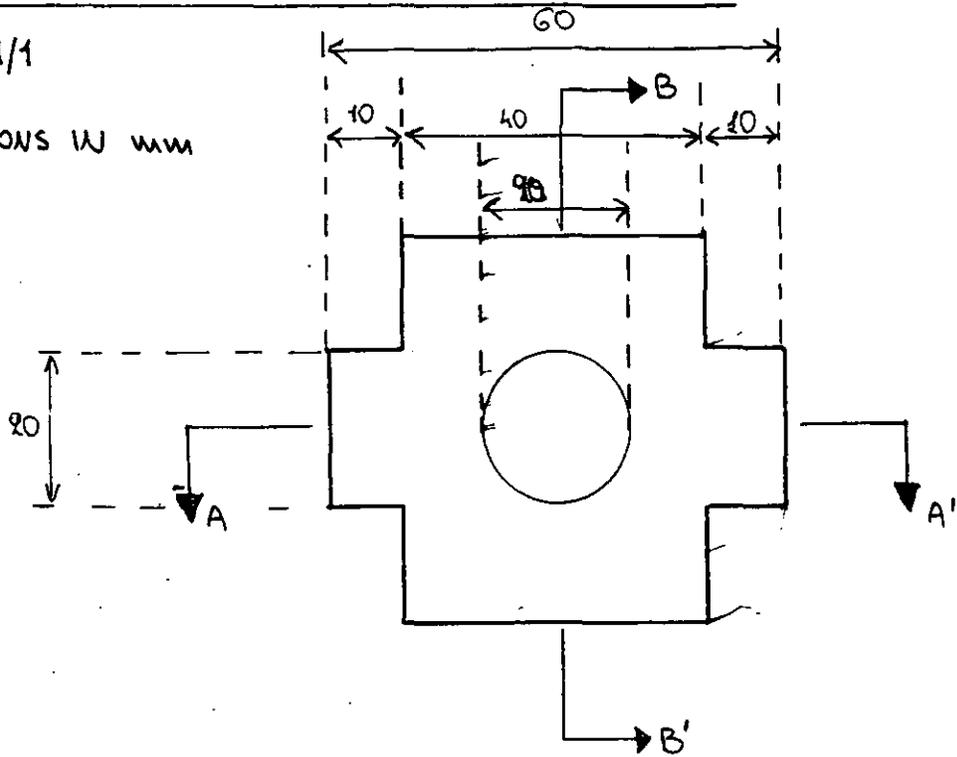
ALL DIMENSIONS IN MM

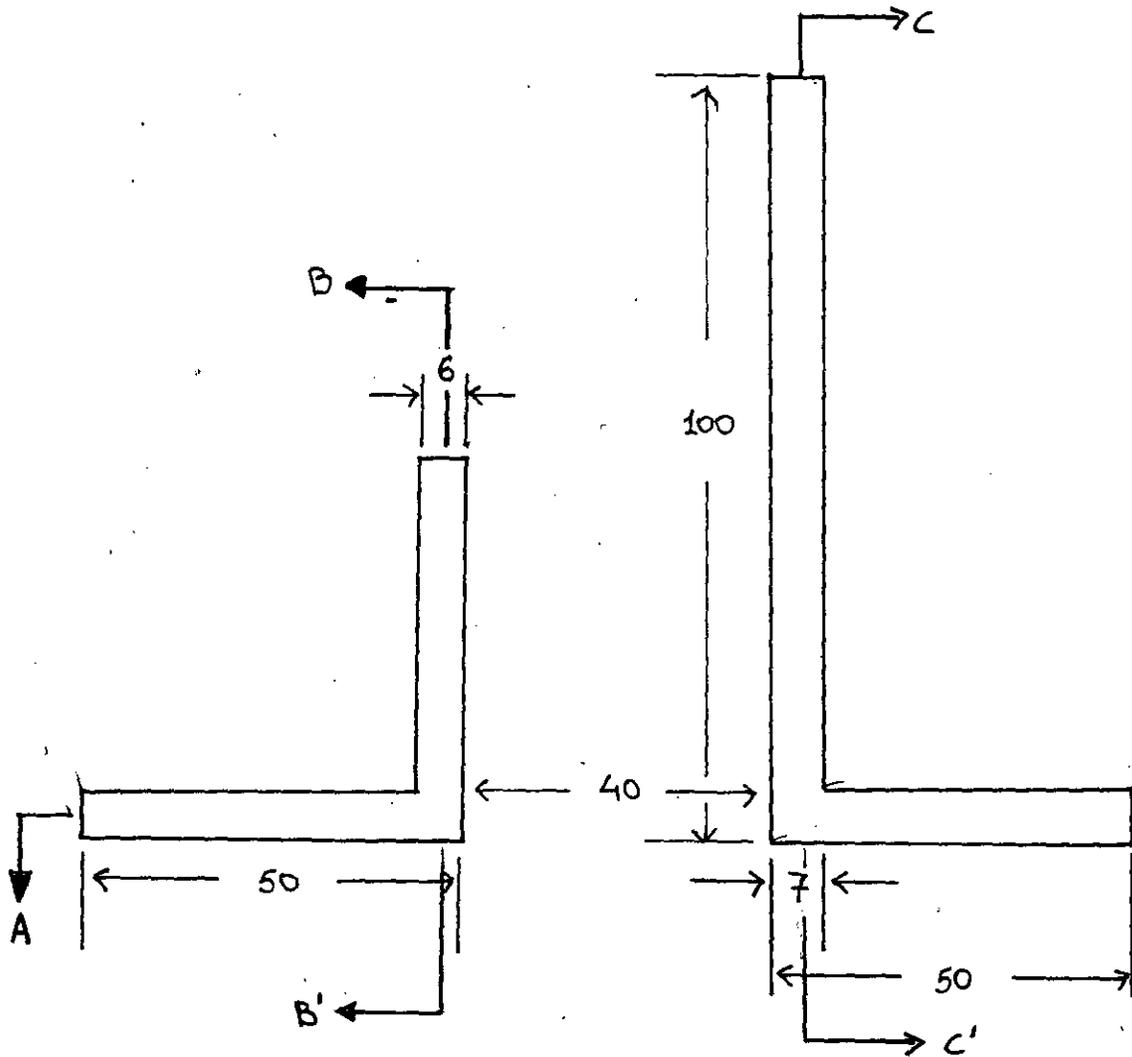
DRAWING 16

ALUMINUM CYLINDER FOR FIXING ROD TO BRACKET

SCALE: 1/1

ALL DIMENSIONS IN MM





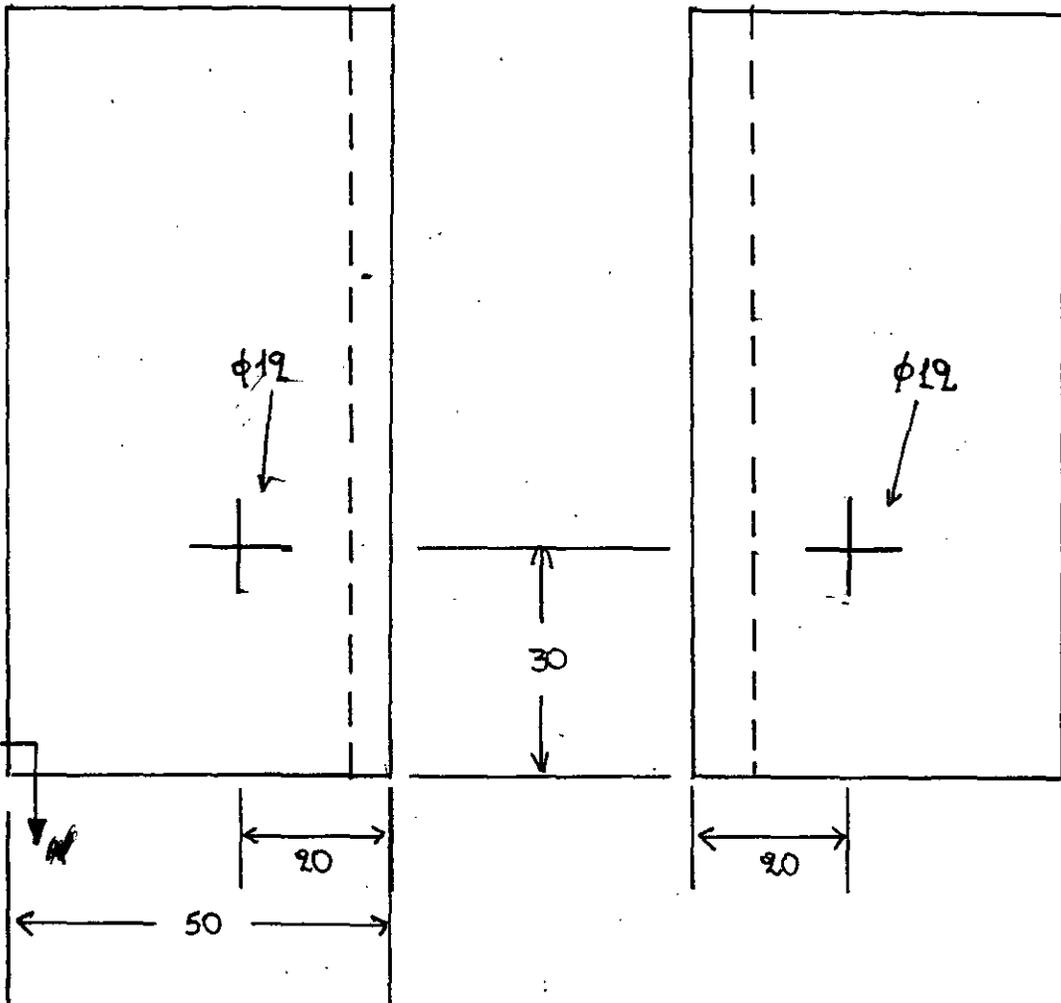
DRAWING 17

STEEL BRACKETS

SCALE: 1/1.

ALL DIMENSIONS IN MM

PLAN AA'



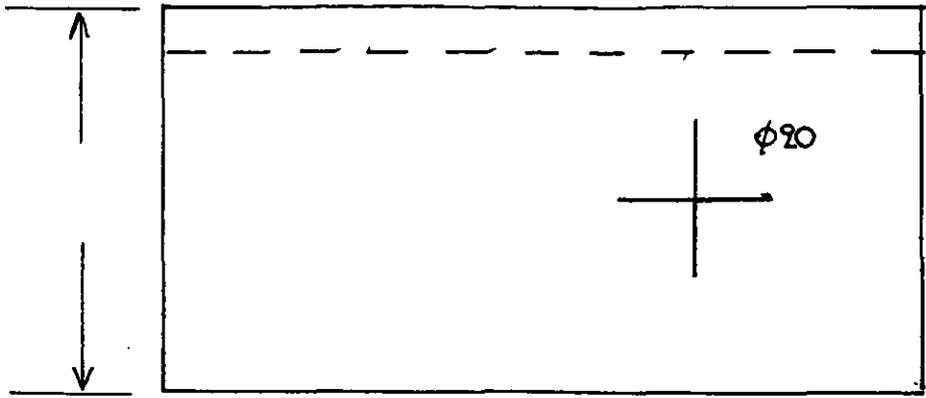
DRAWING 18

STEEL BRACKETS

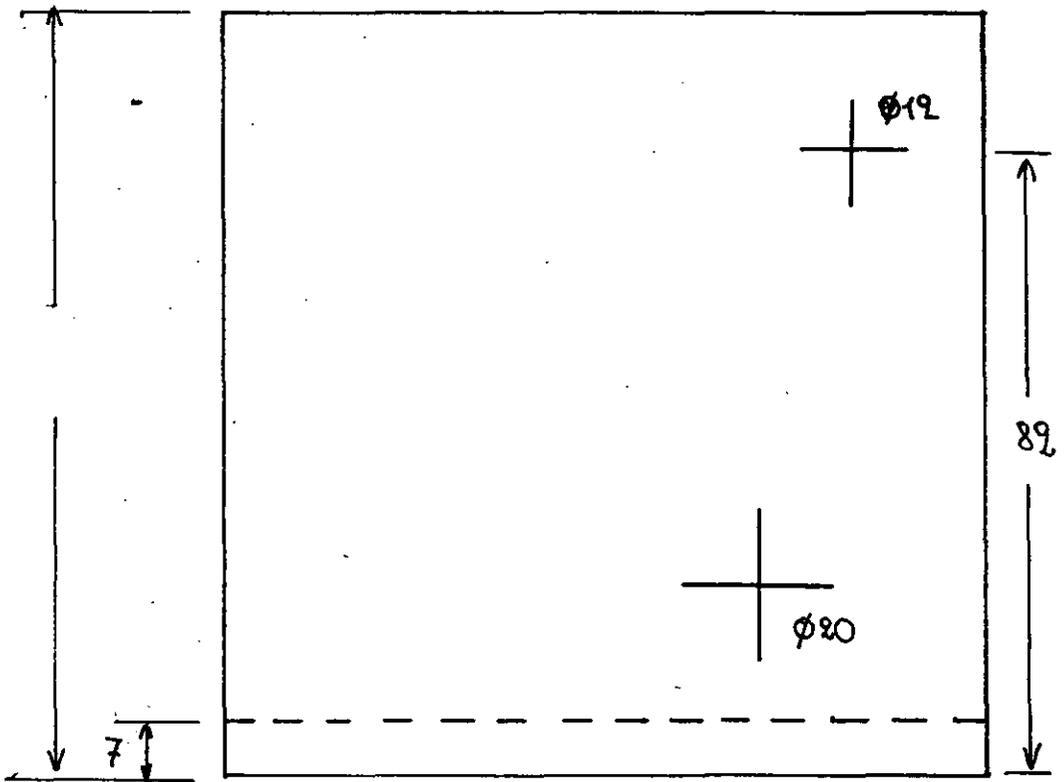
SCALE : 1/1

ALL DIMENSIONS IN MM

PLAN BB'



PLAN CC'



DRAWING 19

STEEL BRACKETS

SCALE 1/2

ALL DIMENSIONS IN MM

REFERENCES

- Boller (1993), *Filter Mechanisms in Roughing Filters*. AQUA vol. 42 N^o 3, pp 174-185.
- Bowen L.P. (1966), *Structural Design in Aluminium*. Hutchinson of London for Alcan Industries Limited.
- Brown D (1988), Horizontal Flow Filtration as an Appopriate Pretreatment method Before Small Slow Sand Filtration in Developing countries, Unpublished MSc Thesis, Newcastle University UK.
- Cairncross S., Feachem R., (1993), *Environmental Health Engineering in the Tropics*, Second Edition. John Wiley & Sons.
- Chadwick A. & Morfett J., (1992), *Hydraulics in Civil Engineering*. E&FN Spon editions.
- Clarke B.A., Lloyd B.J., Crompton J.L., Major I.P (1996), "Cleaning of upflow gravel prefilters in multistage filtration water treatment plants", in Graham N. and Collins R. (eds.) *Advances in Slow Sand and alternative Biological Filtration*, 1996, John Wiley and Sons, England.
- Collins J.O. Cole C.M. Westersund and D.B. Paris (1994). *Assessing roughing filtration design variables*. Water Supply Vol. 12, N^o 1/2,
- Davis J., Lambert R. (1997) *Engineering in Emergencies*. IT Publications on behalf of RedR.
- Fair GM, Geyer J.C., Okun D.A (1968) *Water & Wastewater engineering, Vol 2*. John Wiley & Sons.
- Galvis, J.T. Visscher, J. Fernandez and Fabiola Beron (1993) *Pre - Treatment Alternatives for Drinking Water Supply Systems*. Occasional Paper 22, IRC, 1993.

House S.J and Reed R.A (1997) *Emergency Water Sources: Guidelines for Selection and Treatment*, WEDC, Loughborough University.

IRC (1983), *Small Community Water Supplies*, Technical paper series 18, IRC and John Wiley & Sons.

IRC (1987) *Slow Sand Filter for Community Water Supply*. Technical Paper No 24, IRC and John Wiley and Sons.

Ives K.J. (1975) Capture Mechanisms in Filtration, *Proceedings of the NATO Advanced Studies Institute on The Scientific Basis of Filtration*, edited by Ives K.J Series E, Applied Science # 2, Nordhoff International, pp; 183 - 204

Nothomb (1995) *Portable water treatment units for emergency situations*, MSc Report, WEDC, Loughborough University

Reed R.A (1997), unpublished experiment data

Reed R.A and Kapranis Y. (1998), Roughing filtration with polystyrene beads, *Sanitation and Water for All, Proceedings of the 24th WEDC Conference in Islamabad, Pakistan*, WEDC, Loughborough University.

Schertenleib R. (1992) The water supply situation in developing countries, *Water Treatment Workshop in Zurich 25 - 27 June 1992*, International Reference Centre for Waste Disposal, Switzerland

Schulz C.R. & Okun D.A. (1992) *Surface Water Treatment for Communities in Developing Countries*, Intermediate Technology Publications.

Twort A.C., Law F.M., Crowley F.W., Ratnayaka D.D. (1994) *Water Supply, 4th Edition*, Edward Arnold ed.

UNHCR (1983), *Handbook for emergencies: Field Operations*, UNHCR.

UNHCR (1992), *Water Manual for Refugee Situations*, Programme & Technical Support Section, Geneva.

Watson (1997) *The design and manufacturing of a machine to expand polystyrene beads*, Final year report, Department of manufacturing engineering, Loughborough University.

Wegelin M (1988), Filter News No 1, International Reference Center for Waste Disposal Switzerland.

Wegelin M. (1989), Filter News No 3, , International Reference Center for Waste Disposal Switzerland.

Wegelin M.(1996) *Surface Water Treatment by Roughing Filters*, SANDEC report No 2/96, Swiss Centre for Development Cooperation in Technology and Management (SKAT).

Wegelin M., M. Boller and R. Schertenleib (1987) *Particle Removal by Horizontal - Flow Roughing Filtration*, AQUA Vol. 36 N^o 2, pp 80-90.

Wegelin M., Schertenleib R. and Boller M. (1991) *The decade of Roughing filters - development of a rural water - treatment process for developing countries*, AQUA Vol. 40 No 5, pp.304 – 316.

Wheeler D. (1988) *The Microbiological Benefits of Gravel Prefiltration*, Developing World Water, Vol. 3, Grosvenor Press international.

WHO (1993) *Guidelines for drinking water quality*, volume 1, WHO editions

Wolters, J.E.M. Smet and G. Galvis (1989) *Upflow Roughing Filtration, Pretreatment Methods for Community Water Supply*, IRC, International Water and Sanitation Centre.

