Performance of Flat Roof Outlets

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Contract

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Summary

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HR Wallingford was commissioned by the Construction Sponsorship Directorate of the Department of the Environment (DOE) to carry out a laboratory study on the performance of grated and plain outlets used for drainage of flat roofs. The study involved the testing of four different conventional outlets and of four siphonic systems (where the pipework connected to the outlets is designed to flow full and siphonic action is achieved by excluding or greatly reducing the amount of air normally present in conventional systems). Two of these latter outlets were also tested with a non-siphonic pipework system. The test facility consisted basically of a 2 m x 3 m tank, situated approximately 6 m above discharge level to allow the study of siphonic systems. In the tests the flow was increased in small steps to find the submergence limit of the outlet (ie the transition between weir-type flow and orifice-type flow), and to determine the rating curves of the outlets.

Four main different types of outlet were identified based on the study of shapes and sizes of the outlets, gratings and leafguards and of their relative positions. Guidelines were produced to determine the effective diameter of an outlet for each of these types. Design equations were developed for weir-type flow and orifice-type flow; the effect of gratings or leafguards on the capacity of the outlets tested was also determined.

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1 Introduction

1.1 Scope of study

The present report describes work to investigate the performance of flat roof outlets which was commissioned by the Construction Sponsorship Directorate of the Department of the Environment (DOE). This laboratory study was carried out between April 1995 and March 1996 and arose form a need to obtain specific information on outlets used for drainage of flat roofs. The current British Standard Code of Practice BS 6367: 1983 "Drainage of roofs and paved areas" contains design recommendations for outlets obtained from earlier experimental work commissioned by HR Wallingford on plain outlets installed in gutters. Outlets for flat roofs are normally fitted with leafguards or gratings, and the approach conditions of the flow are often different from those of outlets in gutters. No suitable test data on outlets for flat roofs were available when BS 6367 was prepared, so an approximate (and unverified) method of allowing for the effect of gratings was suggested. The primary objective of the present study, therefore was to develop general design equations for flat roof outlets for use in British and European Standards.

The scope of the study also included an investigation of the performance of siphonic outlets for flat roofs as well as conventional outlets; in the first case, attention had to be given not only to the relationship between the flow rate and head of water on the roof (the rating curve of the outlet), but also to other aspects that are relevant only to siphonic systems. Amongst these are: the ability of the system to exclude air from the pipework and start to act siphonically, and the noise associated with the priming action. Siphonic systems have specific features and design requirements when compared with conventional roof drainage, which are not described in detail in this report. For a detailed review of these systems and assessment of their performance when the outlets are installed in gutters, see May and Escarameia (1996).

As mentioned above, one of the objectives of the study was to measure the depths of water on the roof for various flow rates and hence determine the rating curves of the outlets. It is currently recommended in BS 6367 (1983) that the water depth on flat roofs should not exceed 30 mm to reduce the risk of infiltration of rainwater into the building. A draft European Standard "Gravity Drainage Systems Inside Buildings: Part 3 - Roof Drainage, Layout and Calculation" (prEN 12056-3) has been developed, and it is currently expected that it will be published in 1997 and thus supersede BS 6367. It includes a recommendation that the maximum design depth of water on flat roofs should be 35 mm (although this limit can be raised according to the particular circumstances). It is therefore important to know the discharge that an outlet can convey without exceeding a water depth of 30 or 35 mm; in fact outlets are normally rated according to such a criterion. It was also the objective of the study to produce design equations that would be suitable for a wide variety of outlets, which can vary significantly both in size and shape, and have gratings or leafguards with extremely diverse characteristics. The equations would later be introduced in relevant design documents such as the British Standard.

One of the primary objectives of the "Partners in Technology" programme of the Construction Sponsorship Directorate of DOE, which partly funded this project, is to develop the involvement of industry partners in research. Contacts were, therefore, made with some of the major manufactures of roof damage systems in order to establish a "club" of manufacturers who would supply and, in many cases, install their outlets/systems in HR's test facility. Five companies agreed to participate in the project and it was decided that the results of particular tests should not be directly linked to particular products.

This was done to allow the research to be concentrated on the scientific aspects and to avoid direct comparisons of performance between the various outlets tested. For these reasons the outlets described in this report are denoted by the letters A, B, etc. The five manufacturers involved in the study were (not in order A, B, etc): ACO Fulbora (ACO Technologies Plc), FC Frost Ltd, Fullflow Systems Ltd, Geberit UK, Glynwed Foundries and Sommerhein AB.

The first chapter of this report explains the need for the study and its objectives, and also gives some background information on the theory of flow through roof outlets. Chapter 2 describes the outlets and systems tested, whereas the test facility used is described in Chapter 3. In Chapter 4 the test procedure is outlined and the results are presented. The analysis of results is explained and discussed in Chapter 5, where design equations are also presented based on the test results; Chapter 6 gives the conclusions and recommendations.

1.2 Background theory

It has been found experimentally that the flow, Q, through an outlet such as those used for roofs, can be uniquely related to the head of water above the outlet, h. For small depths of water the outlet is likely to behave as a weir with a length approximately equal to the perimeter of the outlet. In this case, the type of flow through the outlet is called weir flow and the following relationship between Q and h is observed:

$$Q = c_1 h^{1.5} \quad (1)$$

where c_1 is a numerical coefficient of proportionality that depends, amongst other factors, on the length of the weir.

For greater depths of water, the outlet will act as an orifice and the relationship between Q and h changes, as follows:

$$Q = c_2 h^{0.5} \quad (2)$$

where c_2 is another numerical coefficient that depends on the area of the orifice.

Both coefficients c_1 and c_2 need to be determined experimentally in each situation, as they are affected by the approach conditions of the flow into the outlets. These are mainly determined by: the location of the outlet in relation to the building walls or parapets, and by the presence of gratings or leafguards. When the outlet is positioned close to a wall or parapet, this can produce swirling with entry conditions which are far from radial and therefore have to be specifically investigated. Also, gratings or leafguards will cause some obstruction to the flow and, although they may have a positive effect in creating radial flow, the obstruction will normally reduce the capacity of the outlet. Due to the small water depths recommended for flat roofs, it is likely that the flow will be of weir-type for most of the time. However, when the outlet begins to choke (which will lead to submergence of the outlet if the flow rate continues to increase), the flow will transition from weir-type to orifice-type. This transition may be quite sudden for some outlets, or more gradual for others, in which case it is rather difficult to define. Once the outlet is submerged, a small increase in flow rate will produce a steep increase in the head required over the outlet.

The current British Standard, BS 6367 (1983), recommends the use of the following equations to determine the capacity of grated flat roof outlets when test data are not available:

$$Q = \frac{L_w h^{1.5}}{24000} \quad \text{weir flow} \qquad (3)$$

and

$$Q = \frac{A h^{0.5}}{12000} \quad \text{orifice flow} \qquad (4)$$

where Q is the flow (in l/s), h is the head (in mm) above the top of the outlet, L_w is the total length of the openings measured around the perimeter of the outlet (in mm) along which flow enters the outlet and A is the total area of the openings (in mm^2) that are submerged by the flow.

Values of h should be calculated from Equations (3) and (4) and the higher of the two values should be adopted for design. As explained in Section 1.1, this approximate method of applying Equations (3) and (4) to gratings was not verified as test data were not available when BS 6367 was prepared.

2 *Description of outlets and siphonic systems tested*

2.1 General considerations

Conventional drainage systems for flat roofs usually consist of outlets which discharge into vertical rainwater pipes; the connection between the outlet and the rainwater pipe is left unsealed in many practical applications to ensure that a continuous air core is present along the whole length of the pipe. This is a safeguard against negative pressures, which the pipes may not be designed to withstand, and against the uncertainty of having a variable driving head which is dependent on the flow through the system. Recommendations on the design of conventional systems given, for example in BS 6367, were based on ventilated rainwater pipes and therefore the present work on grated outlets was carried out in a compatible way. The conventional outlets tested in the present study discharged freely into the rainwater pipe by means of a short pipe section, as explained later in Section 3. When assembled in this manner, the capacity of conventional systems is determined by the size and shape of the outlet and by the diameter of the tailpipe.

Siphonic systems used for drainage of flat roofs differ from conventional drainage in that the outlets have special geometries to reduce the amount of air flowing into the system, and the pipework connected to the outlets is designed to flow full under design conditions. In flat roofs, where the water depth allowed on the roof is only of the order of tens of millimetres, the driving head is practically equivalent to the difference in level between the outlet and the discharge point. Compared with conventional systems of similar outlet size, (which have a driving head equivalent to the water depth on the roof), the head of siphonic systems is considerably higher; this means that the overall capacity of the system is substantially higher too. However, due to their greater complexity, siphonic systems require a more careful and accurate design in order to perform according to expectations. It can therefore be inferred that the capacity of these systems does not depend solely on the outlet, but also on the pipework that forms the system.For further information on these systems refer to May and Escarameia (1996).

The present study involved the testing of four different conventional outlets; these were installed in the test rig without a direct attachment to the rest of the pipework so that siphoning action could not occur. The test programme also included the assessment of the performance of four different siphonic systems; two of these outlets were also tested with a non-siphonic pipework system so that they could be compared with conventional outlets.

At the start of the test programme, it was agreed that the results would be published in this report without identifying particular products or makes. The outlets were therefore referred to by letters of the alphabet: eg Outlet A, Outlet B, and so on. For simplicity, the siphonic systems tested were also denoted as "Outlets" in spite of the inaccuracy of such a term, as explained in the above paragraphs. Figures 1 and 2 show schematic diagrams of all the outlets tested. The dimensions in the figures as well as the shapes of the outlets are only approximate and are given as indications of the sizes of the outlets.

2.2 Description of the conventional outlets tested

Outlet A

Made of heavy duty PVC, Outlet A was designed primarily for use in flat roofs (see Plates 1 and 2). With an approximate diameter of 200 mm, it included a 95 mm deep sump with a short spigot pipe which allowed tailpipes of different diameters to be used. The leafguard was approximately 315 mm in diameter (at the base) by 185 mm high and made of polypropylene. Tests were carried out with two different pipe sizes: 50 mm and 75 mm (external diameters).

Outlet B

The body of Outlet B had a funnel shape with a vertical spigot 75 mm in diameter (external diameter) and was made of aluminium. With a top diameter of 230 mm, the outlet also included a clamping ring to which the isolating roof membrane is usually attached. Two different types of leafguard were tested: a domed grating which sat inside the outlet on the clamping ring (see Plate 3), and a flat grating which was fixed by bolts to the ring (see Plate 4).

Outlet C

Outlet C was funnel-shaped with a top diameter of 260 mm and a 75 mm diameter spigot (external diameter). All the components of the outlet (ie the outlet body, the leafguard and clamping rings) were made of cast-iron. The leafguard had a domed shape and a height of about 100 mm (see Plate 5).

Outlet D

With a square cross-section at roof level (220 mm x 220 mm) which then tapered to a 75 mm diameter spigot, Outlet D and all its components were fabricated in cast-iron. The leafguard was also square in plan and approximately 60 mm high, as can be seen in Plate 6.

Outlet E

Usually forming part of a siphonic system, Outlet E consisted of a 60 mm deep sump, approximately 180 mm in diameter. The sump was made of stainless steel with a streamlined underside. The spigot was 56 mm in diameter (external diameter) and the leafguard was 75 mm high and made of plastic material, as shown in Plate 7.

Outlet F

Outlet F was similar to Outlet E but bigger in size: the top diameter of the outlet was approximately 295 mm and the spigot external diameter was 75 mm in diameter. The sump depth was, however, equal to that of the smaller outlet, ie 60 mm - see Plate 8.

2.3 Description of the siphonic systems tested

Outlet G

Outlet G was a siphonic outlet which included: a solid air baffle with alternate large and small vanes to straighten the flow, a clamping ring with a 184 mm diameter gravelguard and a dome-shaped leafguard. The outlet was approximately 150 mm in diameter and had a shallow 20 mm deep sump (see Plate 9).

Outlets H and I

These outlets were similar to Outlets E and F, respectively, but for the fact that they were used as part of siphonic systems, ie the outlet tailpipe was sealed to the rest of the pipework . A solid plastic air baffle, with a streamlined underside, is normally part of the outlet to help exclude air and therefore promote siphoning action.

Outlet J

Also used as part of siphonic systems, Outlet J had a sump approximately 85 mm deep , was 275 mm in diameter and had a 75 mm spigot (external diameter). The air baffle consisted of an inverted bowl with perforated sides and slots on the top. The leafguard was made of plastic and was 130 mm high, as shown in Plate 10.

The pipework used in these systems is described later in Section 4.3.

3 *Test rig*

The performance of flat roof outlets was investigated in an existing test rig which was adapted specifically for the study (see Figure 3). The test facility consisted basically of a 2 m x 3 m wooden tank situated approximately 6 m above discharge level to allow the study of siphonic systems as well as conventional outlets. Flow to the tank was introduced from two sides (as opposed to a single entry point), in order to produce uniform flow distribution and smooth entry conditions into the outlets. Baffles were incorporated in the tank for the same purpose, as can be seen in Figure 3.

The test facility was designed as a re-circulating rig, with water being drawn from a sump at ground level and pumped to the tank by means of a pump with a capacity of 30 l/s. The flow through the outlet was then discharged back to the sump by pipework which varied in size depending on whether the pipework was intended to operate conventionally or siphonically.

In the case of conventional outlets, the length of the tailpipe was always kept equal to the hydraulic diameter D_h; the flow from the tailpipe was made to discharge freely into a larger diameter pipe which was not sealed to the tailpipe but was concentric with it. For circular tailpipes the hydraulic diameter D_h is equal to the internal pipe diameter since, by definition $D_h = 4R = 4\pi D^2 / 4\pi D = D$, where R is the hydraulic radius (=cross-sectional wetted area/wetted perimeter), and D is the pipe diameter. The reason for limiting the tailpipe length to D_h was to avoid measuring an artificial increase in discharge caused by longer pipes which will often not be representative of practical roof drainage installations. With tailpipes shorter or equal to D_h, the water nappe remains detached from the walls of the pipe whereas in longer pipe sections the attachment of the nappe can cause negative pressures and result in higher discharge coefficients. In the case of the siphonic outlets the pipework formed part of the system and therefore needed to be included in order to achieve realistic operating conditions. As can be seen in Figure 3, the roof outlets were installed flush with the floor of the tank.

The floor of the tank incorporated a removable square plate in the centre to facilitate the installation and removal of the outlets. The outlets were installed directly on the floor of the tank without inclusion of any material to simulate roof membranes. Two drains were also included in the rig and discharged directly into the sump.

The flow rate was measured by a 200 mm diameter electromagnetic flowmeter (Altometer, type SC80AS) which has an accuracy of ±0.8%of the actual flow. A valve was used to control the flow rate to the rig.

A total of eight tapping points were drilled in the floor of the tank for the measurement of water depths, as shown in Figure 4. Tappings B, C and D were located 1m from either side of the outlet centreline, whereas the two tappings A were set 400 mm away. Preliminary tests showed that, for the range of flows studied, this latter position was sufficiently close to the outlet to give representative measurements of the water depths approaching the outlet, without being so close as to measure the drawdown of the water surface at the entry into the outlet. Tappings A were therefore used in the majority of tests. Transparent flexible tubes were connected to each tapping point and the water depths were read against a scale fixed on a piezometer board.

4 Tests

4.1 Test procedure

The test procedure was basically the same for conventional outlets and for siphonic systems: the flow was increased in small steps until the submergence limit was reached (ie when a small increase in flow corresponded to a steep increase in water depth); after submergence had occurred, the flow was further increased to try to measure the performance of the outlet under such conditions.

Readings were taken of the water depth on the flat roof for each of the flow rates, after allowing sufficient time for establishment of steady conditions in the test rig. The flow increments in the tests of conventional outlets were of the order of 0.5 l/s, but were in general higher in the tests of siphonic systems due to their overall higher capacity. Once the outlet was submerged, even small increments in the flow rate caused the water levels to rise significantly. In theory this situation corresponds to a marked change in the discharge curve of the outlet. However, the transition between an essentially weir-type flow (before the outlet is submerged) to an orifice-type flow (when the outlet becomes submerged), is not always very sharp, particularly when the outlet and/or the leafguard have complex geometries. For this reason, the judgement of the conditions at which the change occurs is necessarily somewhat subjective. In the present tests an outlet was considered to be submerged when an increase in flow caused a steep rise in water depth.

4.2 Conventional outlets

A list of the conventional outlets tested is presented in Table 1. It can be seen in the table that tests were carried out with and without a leafguard or grating covering the outlet. This was done in order to assess the effect of the leafguard on the depth of water on the roof and on the entry conditions into the outlet. In tests A4 and A5 the outlet tailpipe was connected and sealed to the discharge pipe. These tests were outside the main tests but are of interest because they showed a substantial increase in capacity when compared with the adopted configuration. This will be discussed later, in Section 5.

In some of the tests summarized in Table 1 an air baffle was introduced in the outlet (for example Tests E3 and E4). Air baffles are features of siphonic outlets and their objective is to help exclude air from such systems and therefore promote priming. Although not normally used in conventional roof drainage, air baffles were included in some tests to see whether or not they induced higher flow capacities than those obtained in their absence.

The results of the tests are presented in Tables 2 to 7, which also include some observations on the flow conditions at the outlets. Examples of tests with conventional outlets are shown in the following plates: Plate 1 (Test A3, at 3l/s), Plate 2 (Test A5, at 6l/s), Plate 3 (Test B2, at 1.5l/s), Plate 4 (Test B3, at 3.4l/s), Plate 5 (Test C2, at 6.1 l/s) and Plate 6 (Test D2, at 2l/s).

4.3 Siphonic systems

As mentioned in Section 2.3, the tests of siphonic systems involved three manufacturers, one of which supplied two outlets of different sizes for testing. Table 8 lists the outlets tested and it can be seen that, with the exception of tests H2 and H4, all the tests were carried out with air baffles, as these are regular features of siphonic systems. In most tests the standard leafguards were also fitted.

In siphonic systems the design capacity depends not only on the sizes of the outlet and tailpipe, but is also strongly dependent on the layout and size of the pipework that constitute the systems. Therefore it is important to design these systems accurately in order to satisfy the specific requirements of each installation. In the present study, the manufacturers involved were asked to produce a design which was suitable for the conditions of the flat roof rig. These conditions were: a vertical tailpipe of about 1m length and an approximately 3.8 m long horizontal section, followed by a vertical drop of about 5m to the discharge point.

The layout and sizes of the pipes that formed the drainage systems for Outlets G, H and I are shown in Figure 5 and Table 9. It can be seen in the figure that a valve was introduced at the downstream end of the downpipe to control the flow at that point. This valve was part of the system installed by the suppliers of Outlet G, and, as it was left in the rig, the suppliers of Outlets H and I were asked to accommodate it in their design. Both tests with Outlet G presented here were carried out with the same degree of valve closure. The valve was kept completely open in tests H1, H2, I1 and I4 but was partially closed in the other four tests to reduce the capacity of the system to approximately: 6l/s (in tests H3 and H4), 21.5l/s (in test I2) and 12l/s (in Test I3). In each of these cases the setting of the valve was carried out prior to the tests in the following manner: the valve was gradually closed to cause submergence of the outlet at the required flow rate; once the correct valve position was achieved, no further adjustments were made and the tests proceeded as described in Section 4.1. The system designed to incorporate Outlet J is presented diagrammatically in Figure 6, where it can be seen that the control valve was omitted and the pipe diameter was constant along the whole system.

Examples of the tests are shown in: Plate 7 (Test H3, at 2.1l/s), Plate 8 (Test I1, at 18.1l/s) and Plate 10 (Test J1, at 5l/s). Tables 10 to 13 summarize the results of tests carried out with siphonic systems.

5 Analysis and discussion of results

5.1 Rating curves

The values of flow rate and water depth on the roof, which are presented in Tables 2 to 13, were plotted in Figures 7 to 16 to illustrate the stage-discharge curves of each outlet. In these curves the flow rate is given in l/s and the water depth on the roof in mm; for most types of outlet the curves include tests carried out with and without leafguards and, in the case of some siphonic outlets, plots were also produced for tests with and without the air baffles so that their effect on the performance of the systems could be determined.

The limiting capacities of the outlets, which are also discussed in the following sections, were taken as the flow rates for which the flow transitioned from weir-type to orifice-type (see Section 4.1). Mention will also be made in the next sections of the flow rates that corresponded to measured water depths on the roof of 30 mm and 35 mm. These values are, as explained in Chapter 1, the limiting depths recommended at present in BS 6367 and in the draft European Standard prEN 12056-3, respectively.

5.1.1 Conventional outlets

The stage-discharge curves obtained from tests A1, A2 and A3 of Outlet A are presented in Figure 7. Curves for Tests A4 and A5 were not produced since these tests were not carried out with a ventilated tailpipe and would not be comparable with results for other outlets. However, it is interesting to notice in Table 2 that the ultimate capacity of the outlet was greatly increased when the tailpipe was sealed (an increase of more than 600%); this indicates that the system possibly developed a strong siphonic action in which the air was removed from the pipework and the pipes were therefore flowing full. Comparing the curves for Test A1 (with leafguard) and Test A2 (without leafguard), it can be seen that there is an increase of about 20% in the capacity of the outlet when the leafguard is not present.

Figure 8 shows the results obtained for Outlet B: Test B1 (without leafguard), Test B2 (with a domed leafguard) and Test B3 (with a flat leafguard). For flow rates below approximately 5 l/s the three curves are quite similar; the differences are only significant in terms of the limiting capacities. The domed leafguard reduces this capacity by 3% whereas the flat leafguard reduces it by about 18% when compared with the outlet without a leafguard. Outlet B with the domed leafguard produces a water depth on the roof of 30 mm for a flow rate of approximately 8 l/s; with the flat leafguard the outlet becomes submerged before that depth is achieved.

The rating curves for Outlet C are shown in Figure 9: Test C1 (without leafguard) and Test C2 (with leafguard). It can be seen that, although for flows below 5 l/s the two curves are very similar, the limiting capacities of the outlet in the two tests are substantially different, with an increase of 28% when the leafguard is removed. With the leafguard, Outlet C produces 30 mm and 35 mm of water depth on the roof for 7 l/s and about 7.4 l/s, respectively.

The curves produced for Outlet D, which are shown in Figure 10, indicate a significant increase in limiting capacity (around 53%) when the leafguard is not present. It is also apparent in the Figure that the shapes of the two curves are quite different, even for small flows. Water depths of 30 mm and 35 mm are achieved for flows of about 6 l/s and 6.5 l/s, respectively, for the outlet with leafguard.

The results of the four tests carried out with Outlet E are plotted in Figure 11 (two without air baffle - Tests E1 and E2 - and two with the air baffle normally used when the outlet is part of a siphonic system - Tests E3 and E4). It can be seen that the two curves without the leafguard - Tests E1 and E3 - are practically coincident (except for flows close to the limiting capacity), as are the other two curves with the leafguard - Tests E2 and E4.

Figure 12 shows the rating curves for Outlet F. As observed for Outlet E, the two curves without leafguard (Tests F1 and F3) are significantly different from those with leafguard (Tests F2 and F4). Contrary to what was observed in all the other tests, the presence of the leafguard does not appear to decrease the limiting capacity of the outlets (compare Tests F1 with F2 and F3 with F4); in fact, a small increase can be seen with the leafguard in Tests F1 and F2. As for Outlet E, the air baffle appears to reduce the limiting capacity of the outlet, by between 10% and 15%.

5.1.2 Siphonic systems

The rating curves for the siphonic system incorporating Outlet G with and without its leafguard (Tests G1 and G2, respectively) are shown in Figure 13.These two curves are very similar and the capacity of the system (25 l/s) is little affected by the presence or absence of the leafguard. This system was found to discharge approximately 4 l/s and 6 l/s with water depths on the roof of 30 mm and 35 mm, respectively.

All of the four tests of siphonic systems incorporating Outlet H were carried out with the leafguard and are presented in Figure 14. In Tests H3 and H4 the capacity of the system was limited to 6 l/s, as explained in Section 4.3, whereas in Tests H1 and H2 the valve at the downstream end of the pipework was kept completely open. The plot of Test H1 shows an irregularity in the rating curve at about 5 to 6 l/s, when the outlet was observed to become submerged and the water depth increased significantly; however, after about 10 minutes the siphonic action was recovered and the ultimate capacity achieved was about 23 l/s. This phenomena was not observed during Test H2 which was carried out without the air baffle but the water depths measured were significantly higher than in Test H1 for flows above 15 l/s. The presence of the air baffle caused a decrease in the limiting capacity between 8% and 17% (compare Tests H1 and H2, and H3 and H4). In general, Outlet H was found to discharge approximately 5.5 l/s with 30 mm of water on the roof and 6.5 l/s with 35 mm.

All the tests carried out with Outlet I included the leafguard and the results are shown in Figure 15. The differences between the results of the various tests reside mainly in the ultimate capacity of the system; this was determined by adjustment to valve positioned at the downstream end of the pipework (Tests 12 and 13) and by changes in the tailpipe diameter (Test 14). As can be seen in Figure 15 and Table 12, the capacity of the test rig was reached before the outlet became submerged for Test 14. Whatever the pipework in the system, in general terms Outlet I was found to discharge about 8 l/s with 30 mm of water depth on the roof and about 11 l/s with 35 mm of water.

The results of tests with Outlet J (Test J1 with leafguard and Test J2 without leafguard) are plotted in Figure 16. Particularly for flows above approximately 10 l/s, the leafguard tends to increase the values of water depth on the roof. For a water depth of 30 mm, the system with leafguard was found to discharge about 10 l/s and, for a water depth of 35 mm, approximately 12.5 l/s.

5.2 Development of design equations for flat roof outlets

It was mentioned in the Introduction of this report that BS 6367 (Appendix B) recommends the use of weir flow and orifice flow equations for design of outlets installed in roof gutters. The development of these equations was based on experimental measurements carried out in gutters but they did not cover the specific case of grated outlets in flat roofs. The British Standard therefore recommends that grated outlets should be tested to determine their flow capacity; however, if test data are not available, the capacity of grated outlets can be estimated approximately by applying Equations (3) and (4) which are those also recommended for plain rectangular outlets in gutters.

The present tests were carried out with the ultimate objective of developing suitable equations for grated outlets in flat roof conditions. Based on previous experience and on visual observation of the flow during the tests, it was decided to investigate if the data for unsubmerged conditions could be well represented by a weir-type equation. All the data collected in the tests before the outlets became submerged were plotted in a log-log graph (Figure 17) where it can be seen that the power of h in Equation (1) is approximately 1.5. This finding confirms the assumption of weir-type flow for most of the flow conditions in the tests.

5.2.1 Effective diameter

The design equations in BS 6367 for circular outlets depend, amongst other variables, on the effective diameter of the outlet. These equations are of the following form:

$$Q = \frac{D\,h^{1.5}}{K_1} \quad \text{for weir flow} \tag{5}$$

and

$$Q = \frac{D\,h^{0.5}}{K_2} \quad \text{for orifice flow} \tag{6}$$

where K_1 and K_2 are numerical coefficients and D is the effective diameter of the outlet. In order to develop design equations for flat roofs that are compatible with the existing equations for outlets in gutters, it was necessary to define what is meant by "effective diameter" for the case of flat roof outlets. For this purpose, each outlet was carefully inspected and schematic diagrams were produced to help identify the main features and observe the most relevant details.

It was decided to study the shape of each outlet and the position of the leafguard in relation to the outlet (ie whether the leafguard is set inside the outlet bowl or is positioned surrounding the outlet). These parameters are important with weir-type flow, for determining where the water passes through critical depth; the length of the outlet perimeter at this location has an important effect on its flow capacity. The complex shapes of some of the outlets tested, as well as the wide variation in the types of leafguard available, introduced some difficulties, as expected. Because of the variation in shapes of the outlets in the UK market, it is necessary to study the shape of each individual outlet in order to estimate its effective diameter. It is particularly important to notice the relative sizes of the leafguard and outlet and to observe if the outlet contains an internal ring to fix the roof membrane, in which case the point of critical flow may be located at the ring. It is also important to identify the position of gravel guards as they can produce critical flow conditions and therefore determine the effective diameter of the outlet. Four major types were identified from all the outlets tested and are presented in Figure 18.

For the determination of the effective diameter, D, it is recommended to use the following guidelines:

1. Type I - If a gravel guard is present, $D = D_{gravelguard}$

2. Type II - If $1.6 > D_{leafguard} / D_{outlet} > 1.2$, $D = D_{leafguard}$

3. Type III - If $0.8 < D_{leafguard} / D_{outlet} \leq 1.2$, $D = D_{outlet}$

4. Type IV - If $D_{leafguard} / D_{outlet} \leq 0.8$, $D = D_{outlet\ ring}$ (or $D = D_{outlet}$ if the outlet has no clamping ring)

In the above relationships $D_{leafguard}$ corresponds to the basal diameter of the leafguard; if the outlet has a round edge, D_{outlet} is measured from the point where the flow will tend to drop into the outlet , ie from the start of the outlet curvature (see, for example, Outlet B in Figure 1). These guidelines resulted from analysis of the experimental data in terms of the value of the numerical coefficient K_1 in Equation (5); this analysis is explained in detail in the next section.

5.2.2 Weir flow equation

The value of coefficient K_1 in Equation (5) was determined for all the measurements with a leafguard before submergence occurred, taking into account that the effective diameter, D, varies with the size and shape of the outlet. This was done in the following manner: 1. an average value of K_1 was calculated for each outlet; 2. comparison of geometrical data from all the outlets, including gratings, gravel guards and leafguards, led to the determination of effective diameters D (as described in Section 5.2.1) which produced an approximately constant value of K_1 for all outlets (this value of K_1 was determined based on test data for conventional outlets with leafguard); 3. the flow rates for all the data including tests with leafguard and siphonic system were predicted using Equation (5) with the new value of K_1 and were plotted against the measured flows (see Figure 19 - data points represented by diamonds); 4. coefficient K_1 was then revised to incorporate a safety factor of about 1.25 in terms of the flow rate into the design equation (see data points represented by squares in Figure 19). The equation recommended for design of circular outlets in weir-type conditions is:

$$Q = \frac{D\ h^{1.5}}{6000} \tag{7}$$

where Q is in l/s, D is the effective diameter in mm as defined in Sections 5.2.1 and h is in mm. This equation is valid for all the types of outlet and leafguard tested (see Figure 1); in the case of square outlets, D is the side length (also in mm).

The presence of the leafguard produced, in some tests, an increase in the flow depths on the roof when compared with tests without the leafguard (see, for example tests F2 and F1 in Figure 12); however, in several cases, the leafguard was found to have only a marginal effect on water depths, particularly for low flow rates (compare, for example, Tests C1 and C2 in Figure 9). It was also observed that the limiting capacity of outlets can be increased if the leafguard is removed. This increase varied from practically zero to as much as 53% (for the square Outlet D), but in the case of Outlet J the capacity actually decreased slightly by about 3% when the leafguard was not present. These very differing results are obviously due to the wide range of shapes, sizes and types of leafguard tested. It is possible, however, to determine an average value of the coefficient K_1 in Equation (5) for outlets without a leafguard. Adopting the same procedure used for determining Equation (7), the resulting equation (including a safety factor of about 1.25) is given by:

$$Q = \frac{D\,h^{1.5}}{5000} \qquad (8)$$

where Q is in l/s and D and h are in mm. Compared with Equation (7), Equation (8) represents an increase in flow of 20%. In spite of the likely benefits of the removal of the leafguard in the capacity of the outlet, it should be noted that the leafguard is an important part of flat roof drainage systems as it prevents the entry of debris (and particularly ballast stone) into the pipework. Also the leafguard is vital for siphonic outlets in order to prevent the small openings around the air baffles becoming blocked.

5.2.3 Orifice flow equation

The amount of data available from the tests corresponding to the near-submergence of the outlets was substantially less than for weir-type flow conditions; it was also found that the scatter of the results was much greater. This meant that the agreement between measured flows and flows predicted with a design equation would not be as satisfactory as that obtained for weir-type conditions. It should also be noted that the results obtained for the siphonic systems were not included in this analysis. Following the procedure described in the previous section, the value of coefficient K_2 in Equation (6) was determined, and the measured and predicted flows with the value of K_2 were plotted in Figure 20. With a safety factor of 1.2 (see Figure 21), the recommended design equation for orifice-type flow with leafguard is as follows:

$$Q = \frac{D^2\,h^{0.5}}{66000} \qquad (9)$$

where Q is in l/s, D is the effective diameter in mm defined as in Section 5.2.1 and h is also in mm. This equation is not valid for siphonic systems because the flow capacity also depends on the size of the pipework and the overall height of the system. The water depth above which weir-type flow transitions to orifice flow was found to be approximately given by:

$$h > \frac{D}{11} \quad \text{for circular outlets} \qquad (10)$$

Equations (9) and (10) can only be applied with confidence to circular outlets due to the insufficient data collected on square outlets under orifice-type flow conditions.

6 Conclusions and recommendations

1. There has been a long-standing need for data on the flow capacity of grated outlets used for flat roofs since the design formulae given by BS 6367: 1983 "Drainage of roofs and paved areas" were based on data collected from tests of plain outlets installed in gutters. The effect of gratings or leafguards on the capacity of outlets used in flat roofs, where the water depths are limited to a few tens of mm, is likely to be significant.

2. The objectives of the present study were:

   (a) to measure the performance of grated flat roof outlets used in conventional and siphonic drainage systems;
   (b) to produce formulae for the capacity of the outlets to be included in BS 6367 (1983) or the new European Standard prEN 12056-3 which is due to supersede the British Standard in 1997;
   (c) to assist manufacturers to produce improved designs of outlets.

3. A comprehensive laboratory study was carried out to determine the performance of grated outlets used for flat roofs. It involved the testing of six conventional outlets and four outlets used in siphonic systems under a range of flow conditions. The outlets and leafguards tested had a wide variety of shapes and sizes which are schematically presented in Figures 1 and 2.

4. Rating curves for each outlet were obtained and are shown in Figures 7 to 16. For each type of outlet, these figures also allow estimates to be made of the flow rates that correspond to the maximum water depths on the roof recommended by BS 6367 (30 mm) and by the future European Standard (35 mm).

5. In the analysis of the test results two types of flow were considered: weir flow and orifice flow. This follows the approach adopted in BS 6367. For lower water depths on the roof, the outlet acts as a weir and the flow is controlled by its perimeter; as the water depth increases, the outlet acts as an orifice and the flow is controlled by the cross-sectional area of the outlet in plan.

6. Design equations, which incorporate a safety factor of approximately 1.25 compared with the best-fit coefficient, were developed based on data collected both for conventional outlets and siphonic systems. The safety factor allows for some variability in this amount of blockage of the leafguard caused by leaves and other debris.

   The formulae presented are valid only within the range covered in the study, ie for

$$2.5 < \frac{D_{outlet}}{D_{tailpipe}} < 4.5$$

and

$$0.5 < \frac{D_{leafguard}}{D_{outlet}} < 1.6$$

where $D_{tailpipe}$ is the internal diameter of the outlet pipe.

For weir-type flow the capacity of an outlet can be estimated by Equation (7):

$$Q = \frac{D\ h^{1.5}}{6000}$$

where Q is the flow rate in l/s, D is the effective diameter (or side length of a square outlet) in mm and h is the water depth on the roof, also in mm.

This equation was derived assuming that the outlet is installed with a leafguard; if the leafguard is not present, the numerical coefficient in the above equation should take the value of 5000. This represents an increase of 20% in capacity. However, for important practical reasons (such as the need to exclude debris from the drainage pipes), it is recommended to include the leafguard in flat roof installations.

For orifice-type flow, the recommended design equation (Equation (9), which was developed for circular outlets due to insufficient data on square outlets) is as follows:

$$Q = \frac{D^2\ h^{0.5}}{66000}$$

where Q is in l/s, D is in mm and h is also in mm.

7. The calculation of the effective diameter, D, used in the recommended design equations depends on the type of outlet under consideration. During this study it was possible to identify four different types (see Figure 18):

1. Type I - If a gravel guard is present, $D = D_{gravelguard}$

2. Type II - If $1.6 > D_{leafguard} / D_{outlet} > 1.2$, $D = D_{leafguard}$

3. Type III - If $0.8 < D_{leafguard} / D_{outlet} \leq 1.2$, $D = D_{outlet}$

4. Type IV - If $D_{leafguard} / D_{outlet} \leq 0.8$, $D = D_{outlet\ ring}$ (or $D = D_{outlet}$ if the outlet has no clamping ring)

In the above relationships $D_{leafguard}$ corresponds to the basal diameter of the leafguard; if the outlet has a round edge, D_{outlet} is measured from the point where the flow will tend to drop into the outlet , ie from the start of the outlet curvature (see, for example, Outlet B in Figure 1).

8. Partly due to the complex shape of the leafguards, it was found in the tests that the transition between weir and orifice flow is not always well defined, and in some cases can be very gradual. It was, however, possible to determine an approximate relationship that defines the transition point for circular outlets. This relates the effective diameter of the outlet with the head of water on the roof and is given by Equation (10):

$h > \frac{D}{11}$ for circular outlets.

9. The study also allowed some conclusions to be drawn regarding the specific case of siphonic systems used for drainage of flat roofs. All the systems tested were found to have capacities similar to those predicted by the manufacturers, but it was apparent that careful design of the pipework is necessary to guarantee adequate performance. Inadequate pipe size can impair the priming of the system and eventually give rise to surging and violent expulsion of air. With adequate design, the siphonic systems tested showed smooth operation conditions and low levels of noise.

10. Although the air baffle is an essential feature for outlets in siphonic systems, the tests provided some interesting information. A comparison of tests carried out with and without the air baffle, showed that the design capacity of the system was reduced by between 8 and 17% when the baffle was present. This effect was only noticeable on the value of the limiting capacity and was not appreciable at lower flow rates. The obstruction to the flow caused by the air baffle, which promotes the exclusion of air and therefore the priming of the system is believed also to accelerate the transition from weir to orifice flow and therefore the submergence of the outlet.

11. For grated flat roofs outlets with shapes that differ significantly from the types tested, it is recommended to carry out laboratory measurements to determine their capacities.

7 Acknowledgements

The collaboration from the following companies, who provided roof outlets and drainage pipework for testing is gratefully acknowledged: ACO Fulbora (ACO Technologies plc), FC Frost Ltd, Fullflow Systems Ltd, Geberit UK, Glynwed Foundries and Sommerhein AB. Some of the laboratory tests described in this report were carried out with the assistance of Ms C Hide.

8 References

1 BS 6367: 1983. "Drainage of roofs and paved areas". British Standards Institution, 1983.

2 European Standard "Gravity Drainage Systems Inside Buildings: Part 3 - Roof Drainage, Layout and Calculation" prEN 12056-3. Draft version of 20.1.95.

3 May R W P and Escarameia M, 1996. "Performance of Siphonic Drainage Systems for Roof Gutters". HR Wallingford Report SR 463.

Tables

Table 1 Details of test conditions for conventional outlets

Outlet	Tailpipe int. diameter (mm)	Leafguard	Ventilated tailpipe	Air baffle	Test number
A	50	✓	✓	x	A1
	50	x	✓	x	A2
	75	✓	✓	x	A3
	75	✓	x	x	A4
	75	x	x	x	A5
B	75	x	✓	x	B1
	75	✓ domed	✓	x	B2
	75	✓ flat	✓	x	B3
C	75	x	✓	x	C1
	75	✓	✓	x	C2
D	75	x	✓	x	D1
	75	✓	✓	x	D2
E	52	x	✓	x	E1
	52	✓	✓	x	E2
	52	x	✓	✓	E3
	52	✓	✓	✓	E4
F	70	x	✓	x	F1
	70	✓	✓	x	F2
	70	x	✓	✓	F3
	70	✓	✓	✓	F4

Table 2 Results of tests with Outlet A

Test	Q (l/s)	Water depth (mm)	Observations
A1	1.5	11.8	
	2.0	12.5	
	2.5	16.8	Choking at outlet
	3.0	Levels not stabilized	Outlet submerged
A2	1.5	9.5	
	2.0	10.5	
	2.5	12.0	
	3.1	Levels not stabilized	Outlet submerged
A3	1.5	9.0	
	2.0	12.0	
	2.7	16.0	
	3.7	21.0	
	4.8	24.4	
	5.0	Levels not stabilized	Outlet submerged
A4	1.5	12.0	
	2.0	14.0	
	2.5	17.0	
	3.0	19.0	
	3.5	21.0	
	4.1	24.0	
	5.0	27.0	
	6.4	33.0	
	9.6	41.0	
	14.2	52.0	
	19.5	60.0	
	23.3	72.0	
	26.6	76.5	
	28.6	79.0	
	30.5	84.5	
	32.0	87.5	Outlet still not submerged
A5	1.5	7.5	
	2.0	10.0	
	4.0	17.0	Choking at outlet
	6.0	21.5	
	10.1	33.5	
	14.2	41.0	Outlet still not submerged

Table 3 Results of tests with Outlet B

Test	Q (l/s)	Water depth (mm)	Observation
B1	1.6	8.0	
	2.0	10.0	
	2.8	13.0	
	3.2	14.0	
	4.3	18.0	
	5.2	21.0	
	6.4	25.0	
	6.9	26.0	
	7.9	28.0	Choking at outlet
	9.0	Levels not stabilized	Outlet submerged
B2	1.5	9.0	
	2.0	10.0	
	2.7	11.5	
	3.3	14.5	
	4.2	17.0	Choking at outlet
	5.3	19.0	
	6.3	23.0	
	6.8	25.0	
	7.9	30.0	
	8.7	Levels not stabilized	Outlet submerged
B3	1.5	8.5	
	2.0	11.0	
	2.7	13.5	
	3.4	15.5	Choking at outlet
	4.2	18.5	
	5.2	23.0	
	6.2	24.0	
	6.8	26.5	
	7.6	Levels not stabilized	Outlet submerged

Table 4 Results of tests with Outlet C

Test	Q (l/s)	Water depth (mm)	Observations
C1	1.5	8.0	
	2.7	12.0	
	3.3	14.0	
	4.2	17.5	
	5.3	19.5	
	6.2	21.5	Choking at outlet
	6.9	23.5	
	7.8	24.5	
	8.1	25.5	
	8.7	27.5	
	9.3	30.0	
	9.6	33.0	
	10.1	56.0	
	10.4	67.5	
	11.1	Levels not stabilized	Outlet submerged
C2	1.5	7.0	
	2.0	9.0	
	2.7	11.5	
	3.3	12.5	
	4.2	17.5	Choking at outlet
	5.1	19.5	
	6.1	24.0	
	6.9	30.5	
	7.9	46.5	
	8.7	Levels not stabilized	Outlet submerged

Table 5 Results of tests with Outlet D

Test	Q (l/s)	Water depth (mm)	Observations
D1	1.5	9.5	
	1.9	10.0	
	2.8	13.5	
	3.3	15.5	
	4.3	18.5	
	5.1	23.0	
	6.2	25.0	Choking at outlet
	6.9	26.0	
	7.7	26.5	
	8.3	30.0	
	9.4	32.5	
	10.4	Levels not stabilized	Outlet submerged
D2	1.6	8.0	
	2.0	10.5	
	2.8	14.5	
	3.3	16.5	
	4.3	23.0	Choking at outlet
	5.1	25.5	
	6.3	33.0	
	6.8	Levels not stabilized	Outlet submerged

Table 6 Results of tests with Outlet E

Test	Q (l/s)	Water depth (mm)	Observations
E1	1.4	7.0	
	2.1	11.0	
	2.7	14.0	
	3.3	16.0	Choking at outlet
	3.7	20.0	
	4.3	Levels not stabilized	Outlet submerged
E2	1.5	11.0	
	2.0	15.0	
	2.5	17.5	
	3.1	20.5	
	3.7	23.0	Choking at outlet
	3.9	Levels not stabilized	Outlet submerged
E3	1.5	8.0	
	2.0	10.0	
	2.7	14.0	
	3.3	16.0	Choking at outlet
	3.6	Levels not stabilized	Outlet submerged
E4	1.5	12.0	
	1.9	14.5	
	2.6	17.5	
	3.3	24.5	
	3.5	Levels not stabilized	Outlet submerged

Table 7 Results of tests with Outlet F

Test	Q (l/s)	Water depth (mm)	Observations
F1	1.4	6.5	
	2.5	9.0	
	3.7	13.0	Choking at outlet
	4.6	15.5	
	5.9	18.5	
	6.9	21.5	
	7.5	Levels not stabilized	Outlet submerged
F2	1.4	10.0	
	2.8	14.0	
	3.3	16.0	
	4.6	19.5	Choking at outlet
	5.5	21.5	
	6.8	27.0	
	7.8	Levels not stabilized	Outlet submerged
F3	1.4	7.0	
	2.5	10.0	
	3.5	12.5	
	4.8	16.0	
	5.7	18.5	
	6.8	Levels not stabilized	Outlet submerged
F4	1.7	12.0	
	2.5	13.0	
	3.3	16.0	
	4.6	20.0	
	5.5	22.0	Surging at outlet
	6.3	26.5	
	6.8	Levels not stabilized	Outlet submerged

Table 8 List of siphonic outlets tested

Outlet	Outlet pipe size Int diameter (mm)	Leafguard	Air baffle	Test number
G	69	✓	✓	G1
	69	x	✓	G2
H	52	✓	✓	H1
	52	✓	x	H2
	52	✓	✓	H3*
	52	✓	x	H4*
I	69	✓	✓	I1
	69	✓	✓	I2**
	69	✓	✓	I3***
	69	✓	✓	14✪
J	69	✓	✓	J1
	69	x	✓	J2

* System set up for capacity equal to 6 l/s

** System set up for capacity equal to 21.5 l/s

*** System set up for capacity equal to 12 l/s

✪ 110 mm diameter tailpipe

Table 9 Pipe diameters in siphonic systems G, H and I

Pipe number	Test number	Ext. Diameter (mm)	Int. Diameter (mm)
1, 2, 3	G1, G2, H1-H4, I1-14	110	104
4	G1, G2, H1-H4, I1-14	75 110	69 104
5	G1, G2, H1-H4, I1-I3	75	69
	14	110	104

Note: See Figure 5

Table 10 Results of tests with siphonic system G

Q (l/s)	Water depth (mm)	Observations
Test G1		
1.7	20	
3.6	29	
7.0	36.5	
10.1	42.5	
13.6	49	
16.1	54	
21.6	61.5	
23.8	65.5	
25.2	Levels not stabilized	Outlet submerged
Test G2		
1.6	18	
3.5	27	
7.0	37	
10.0	43	
13.0	45	
16.2	51.5	
21.5	60.5	
25.0	Levels not stabilized	Outlet submerged

Table 11 Results of tests with siphonic system H

Q (l/s)	Water depth (mm)	Observations
Test H1		
1.4	12.5	
2.0	15	
2.6	18.5	
3.4	21.5	
4.0	24.5	
5.0	28.5	
5.7	47.5	Intermittent submergence
6.3	53	Intermittent submergence
7.0	34.5	
8.2	37	
9.0	39.5	
9.7	41.5	
11.0	44.5	
12.2	47	
14.3	51.5	
16.0	54.5	
17.5	58.5	
19.4	59.5	
20.5	67.5	
22.2	70.5	
23.5	Levels not stabilized	Outlet submerged

Table 11 Results of tests with siphonic system H continued

Test H2		
1.4	12	
2.5	19.5	
4.0	26	
5.1	30	
5.4	31.5	
6.1	34	
6.8	37	
7.4	39	
8.3	41	
9.4	44	
10.2	45.5	
10.9	47.5	
12.6	52.5	
14.4	56.5	
16.3	67	
17.3	69	
18.2	70.5	
19.1	73	
20.4	76	
21.6	79	
22.8	80.5	
23.7	81.5	
24.5	83.5	
25.3	Levels not stabilized	Outlet submerged
Q (l/s)	Water depth (mm)	Observations
Test H3		
1.5	12	
2.1	15.5	
2.5	18	
3.1	21	
3.8	24	
4.2	25.5	
4.9	28	
5.6	30	
6.1	31.5	
6.8	35.5	
8.0	Levels not stabilized	Outlet submerged

Table 11 Results of tests with siphonic system H continued

Test H4		
1.5	12	
2.2	17	
2.8	20.5	
3.3	22	
4.1	25	
4.8	28	
5.5	31.5	
6.7	35	
7.4	38	
8.4	41	
9.4	Levels not stabilized	Outlet submerged

Table 12 Results of tests with siphonic system I

Q (l/s)	Water depth (mm)	Observations
Test I1		
1.5	10	
2.7	14	
3.6	17	
5.1	21	
6.4	25	
7.4	26	
8.8	29	
10.5	33	
12.5	36	
15.1	41	
18.1	45	
20.3	49	
22.9	52.5	
24.4	56	
25.4	56.5	
26.3	58	
26.9	59	
27.7	59.5	
28.1	62	
28.7	62.5	
29.5	70	
30.1	Levels not stabilized	Outlet submerged
Test I2		
1.6	10	
2.6	14	
3.9	18.5	
5.2	22	
6.1	25	
7.3	28	
8.7	30.5	
9.0	32	
10.2	35	
12.5	37.5	
13.7	39	
15.3	42.5	
16.7	45	
17.7	46	
19.0	48	
19.7	50	
20.2	Levels not stabilized	Outlet submerged

Table 12 Results of tests with siphonic system I continued

Q (l/s)	Water depth (mm)	Observations
Test I3		
1.4	9	
2.5	16	
3.8	18	
5.9	23.5	
8.3	29.5	
10.2	Levels not stabilized	Outlet submerged
Test I4		
1.5	10.5	
2.5	16.5	
5.3	23	
7.8	29.5	
8.1	32	
10.0	35	
12.8	40	
15.1	44	
17.6	48	
19.9	51.5	
22.6	54.5	
25.0	59	
27.3	61.5	
30.0	63	
32.5	66.5	
35.1	72.5	
35.9	72.5	
36.2	74	The capacity of the test rig was reached

Table 13 Results of tests with siphonic system J

Q (l/s)	Water depth (mm)	Observations
Test J1		
1.6	11	
3.0	14	
5.0	21	
7.2	23	
9.3	28	
11.2	32	
12.0	34	
12.7	35	
13.5	37	
14.0	41	
16.3	42.5	
18.3	46	
20.0	Levels not stabilized	Outlet submerged
Test J2		
1.8	10	
3.0	13	
5.0	19	
7.0	22	
9.3	26	
11.1	29	
12.1	31.5	
15.2	36	
17.8	41	
19.1	44.5	
19.5	Levels not stabilized	Outlet submerged

Figures

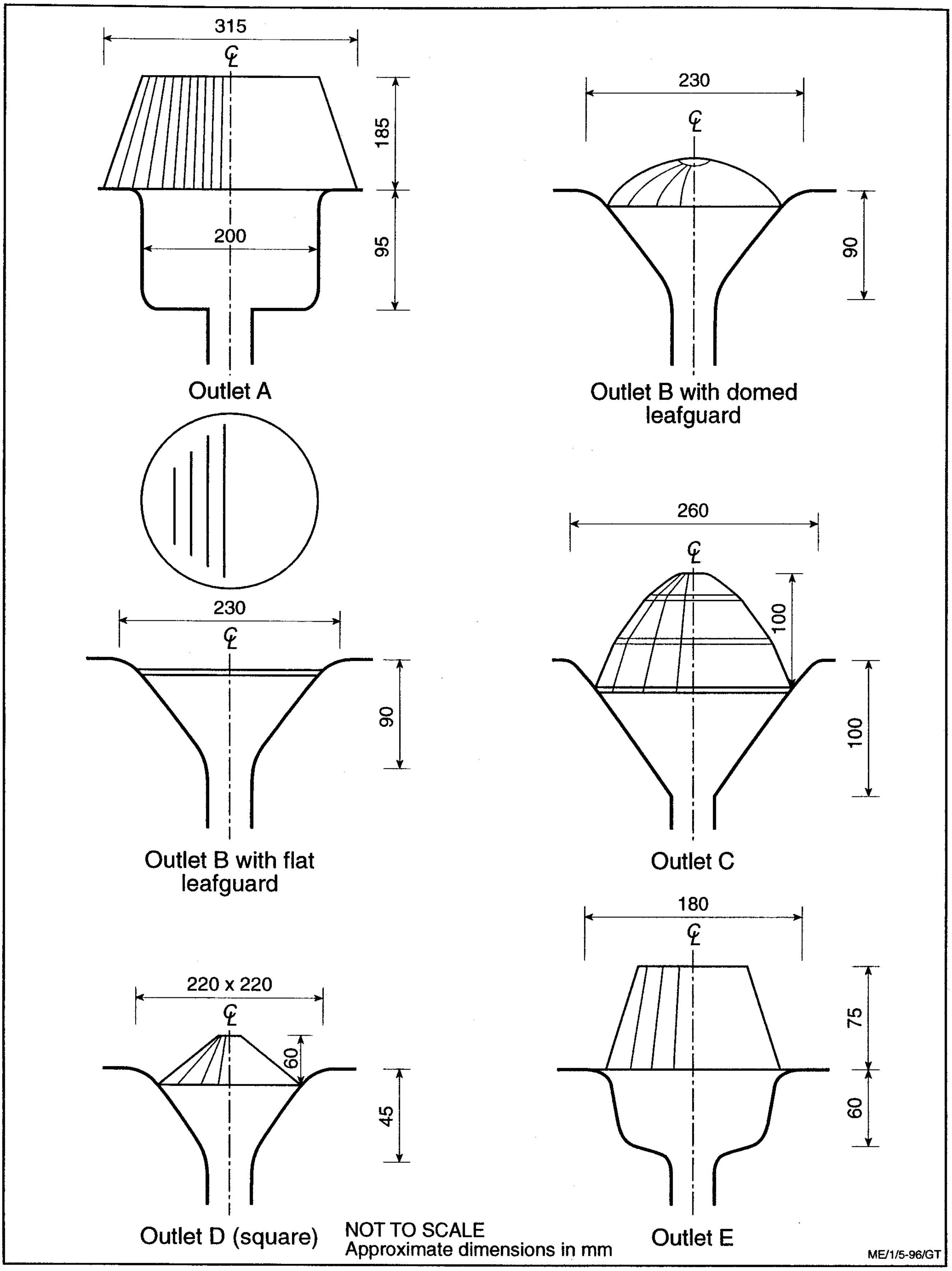


Figure 1 Schematic diagrams of outlets A, B, C, D and E

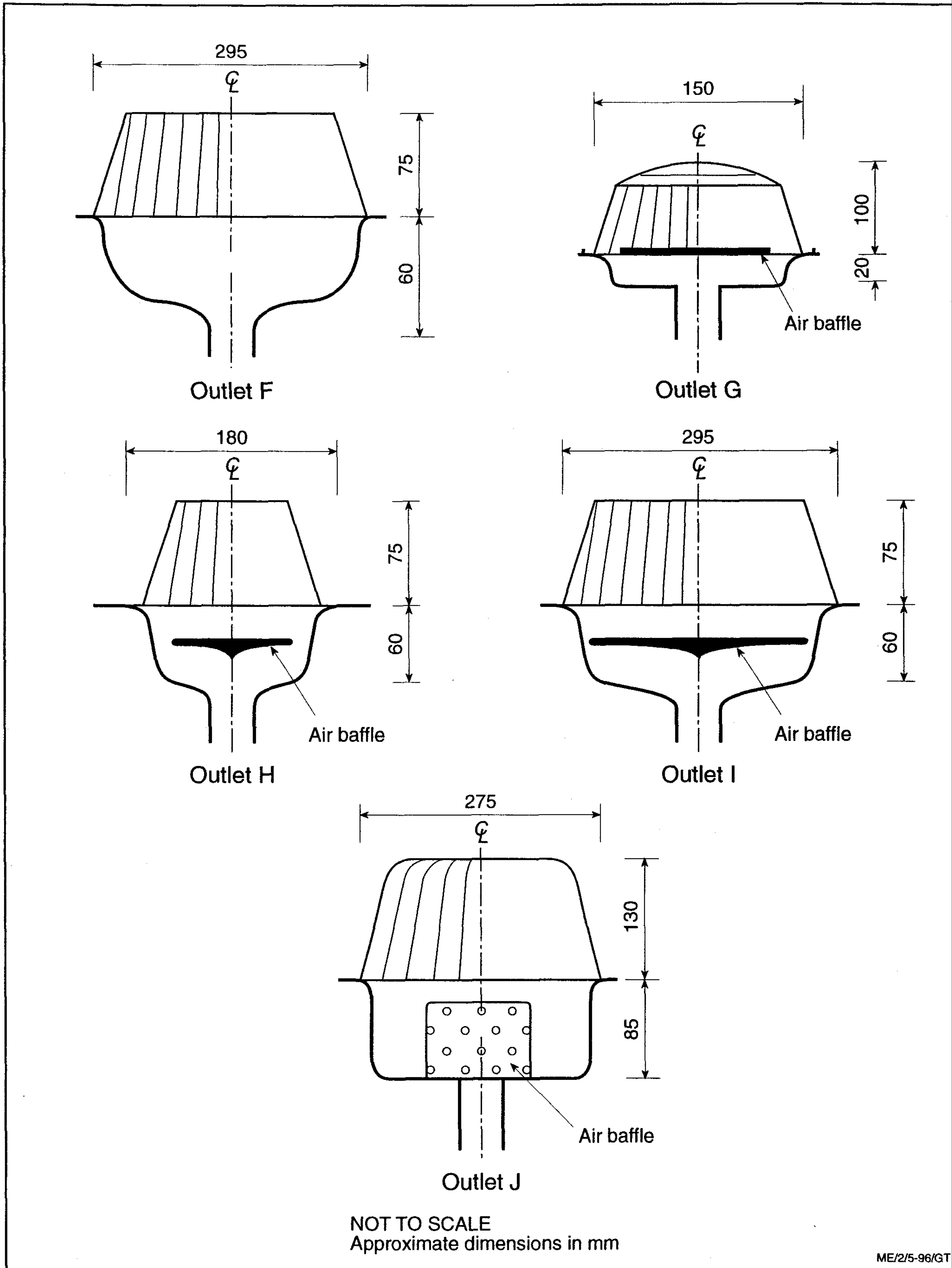
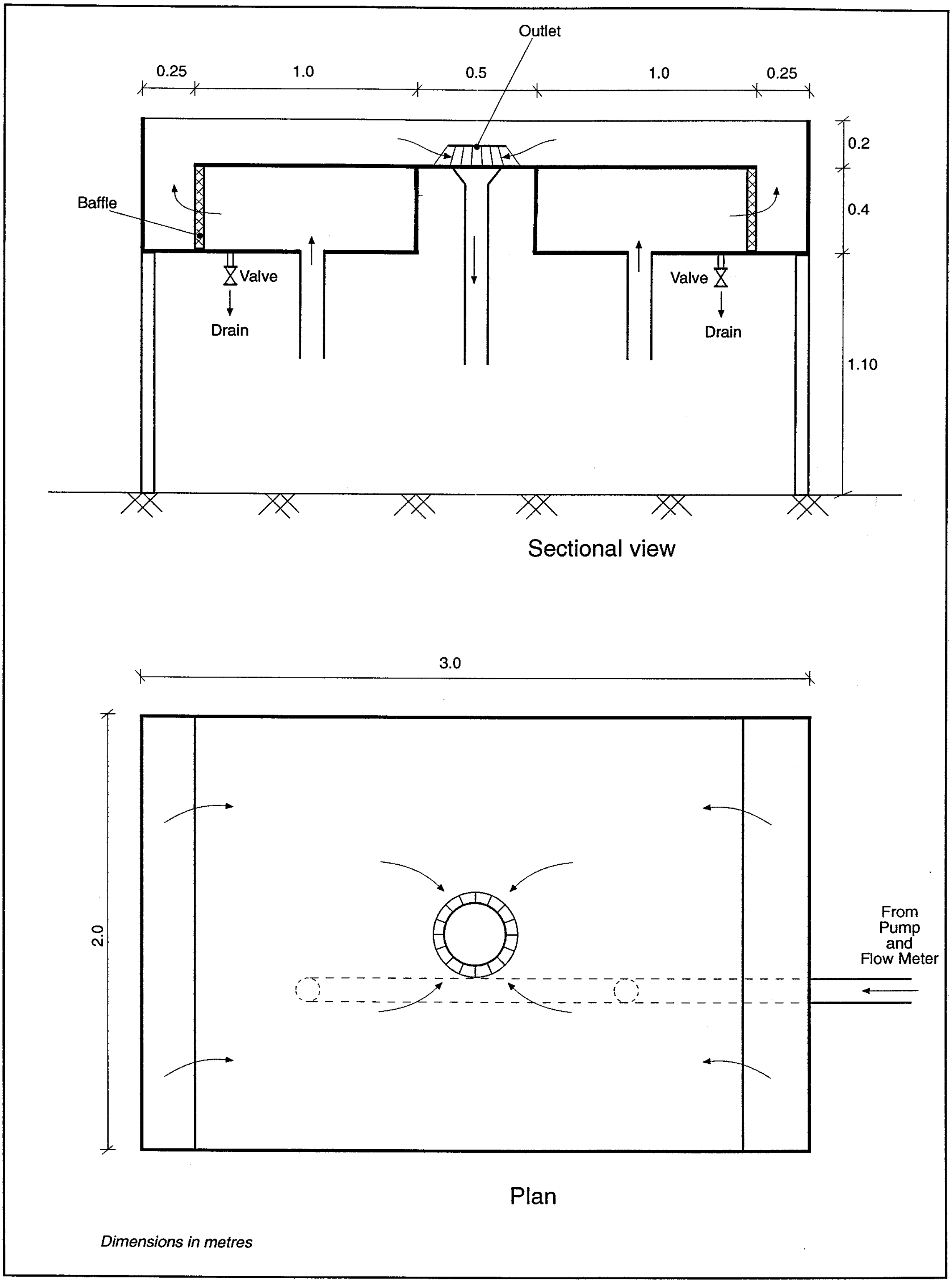
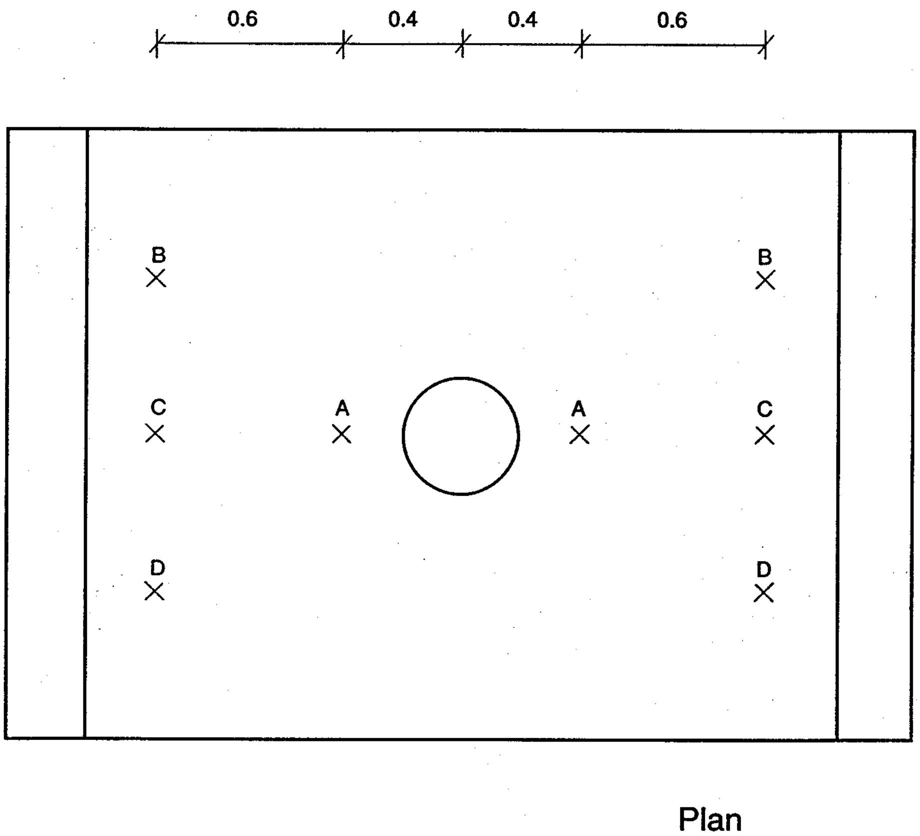


Figure 2 Schematic diagrams of outlets F, G, H, I and J



ME/1/1-96/ f.line

Figure 3 Schematic of test rig



Dimensions in metres

ME/2/1-96/ f.line

Figure 4 Location of tapping points

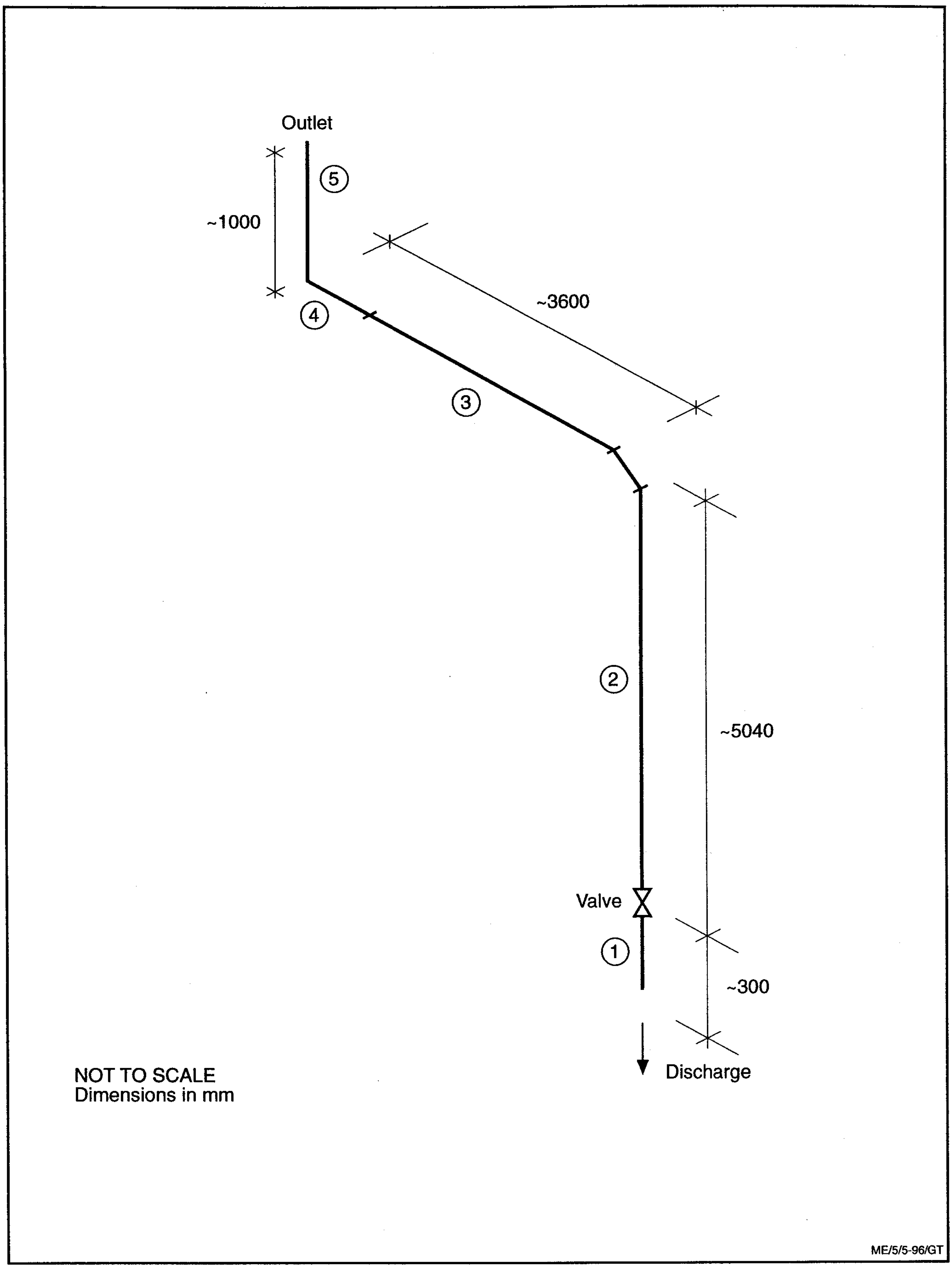


Figure 5 Schematic diagrams of siphonic systems G, H and I

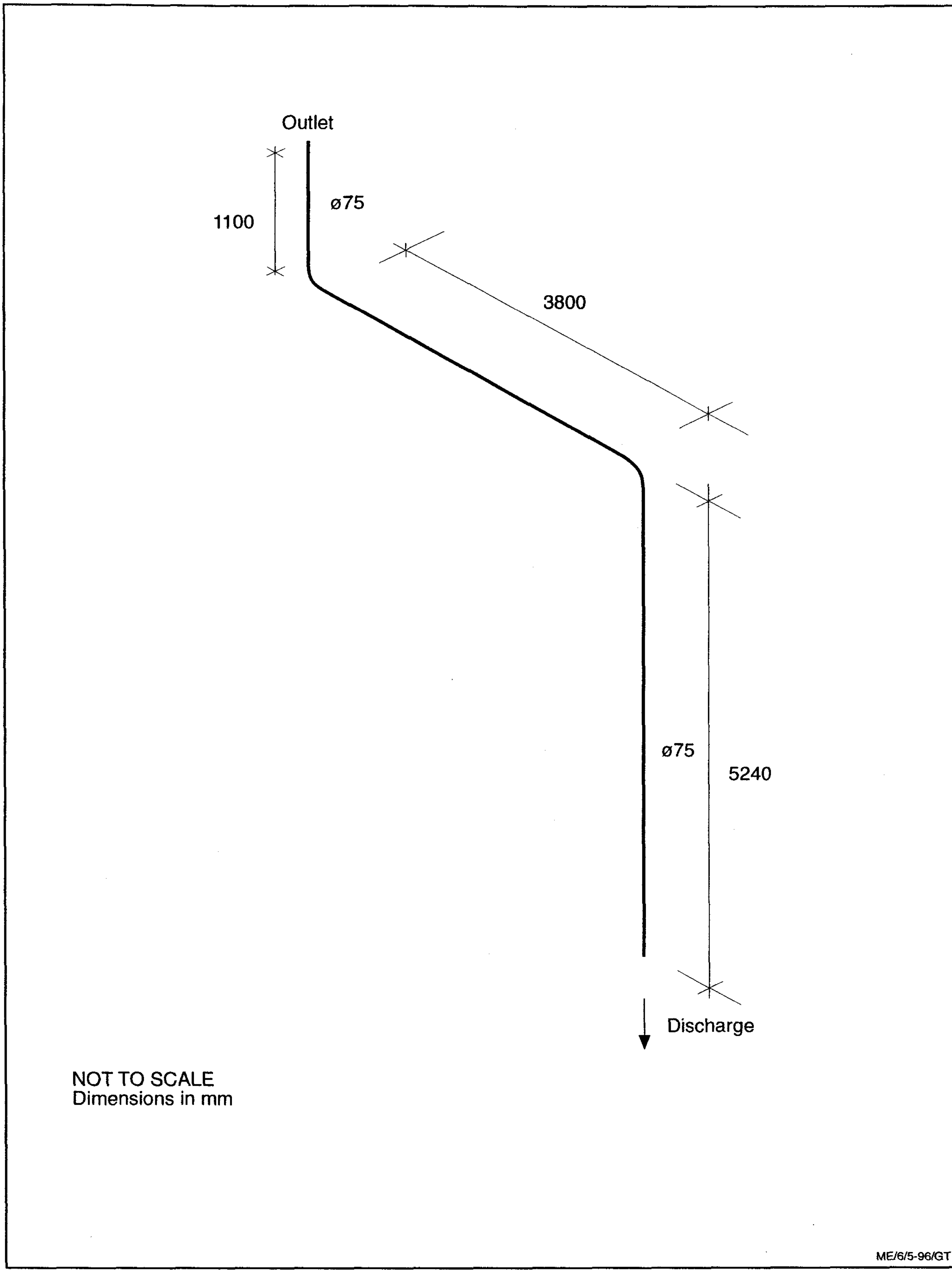


Figure 6 Schematic diagram of siphonic system J

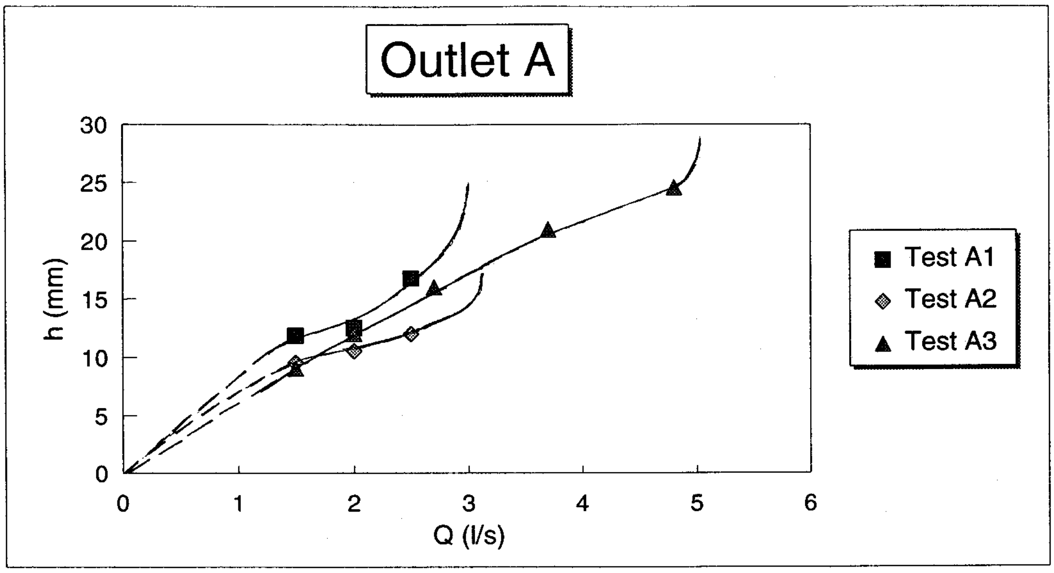


Figure 7 Rating curve of Outlet A

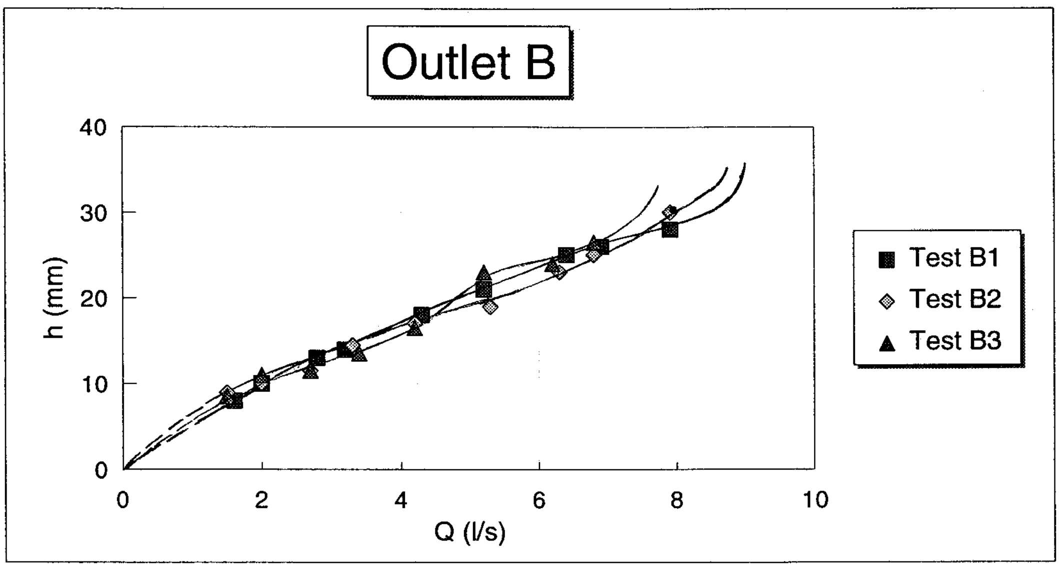


Figure 8 Rating curve of Outlet B

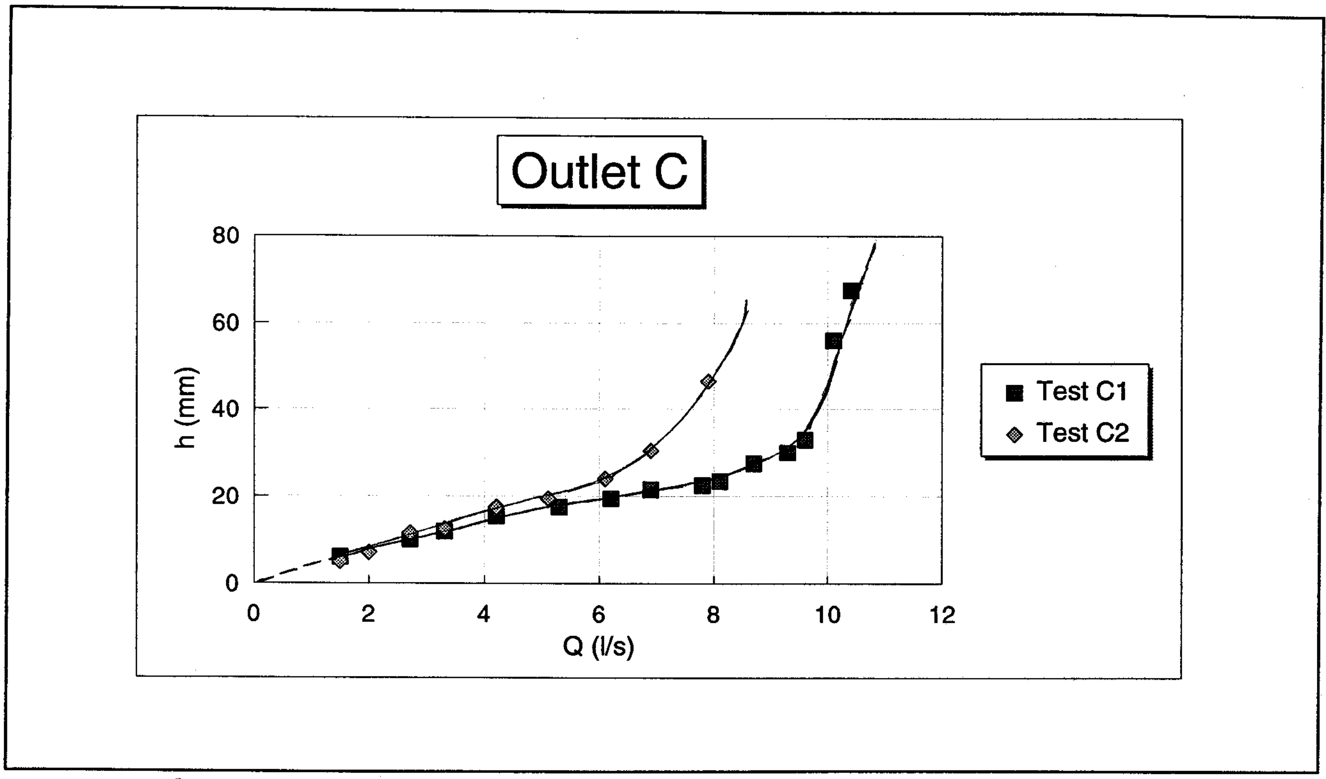


Figure 9 Rating curve of Outlet C

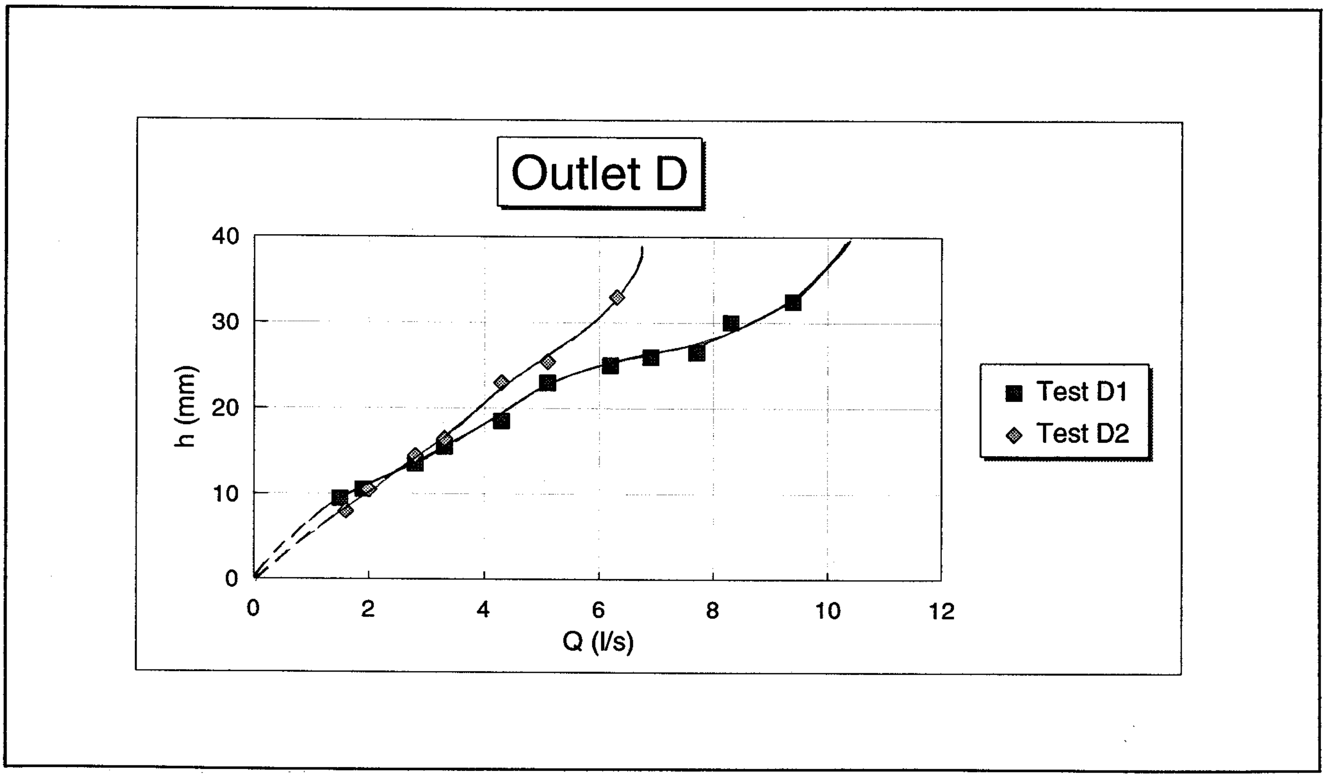


Figure 10 Rating curve of Outlet D

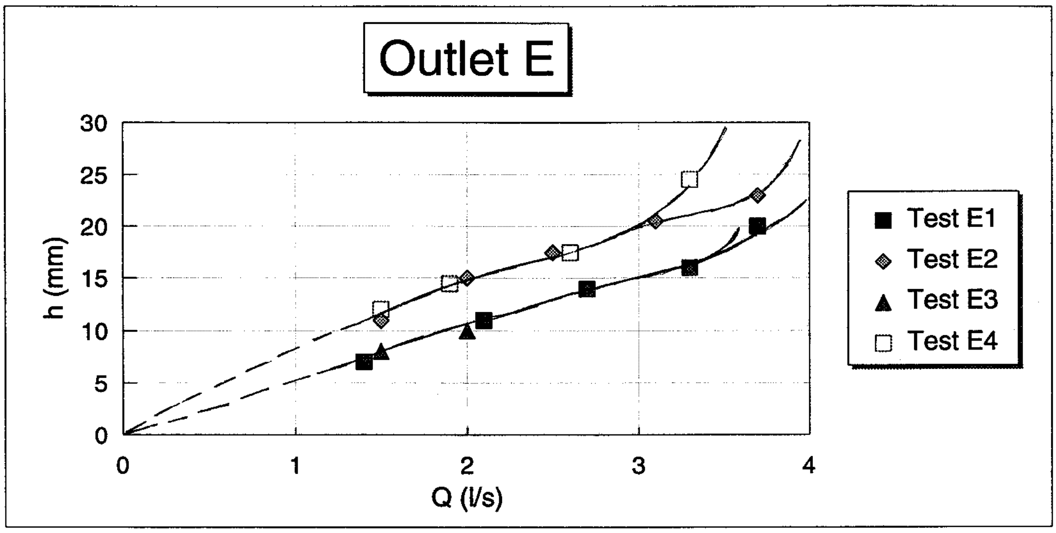


Figure 11 Rating curve of Outlet E

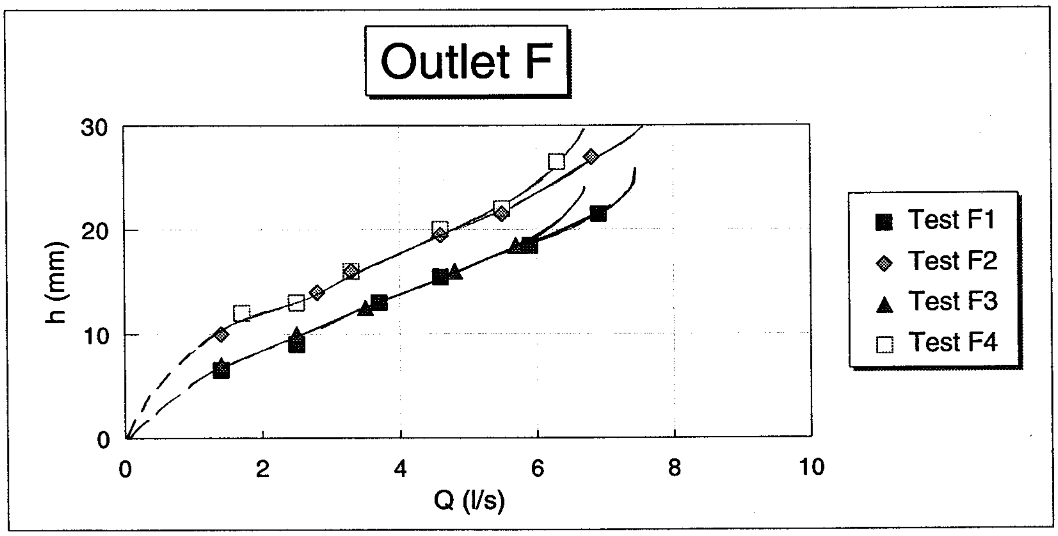


Figure 12 Rating curve of Outlet F

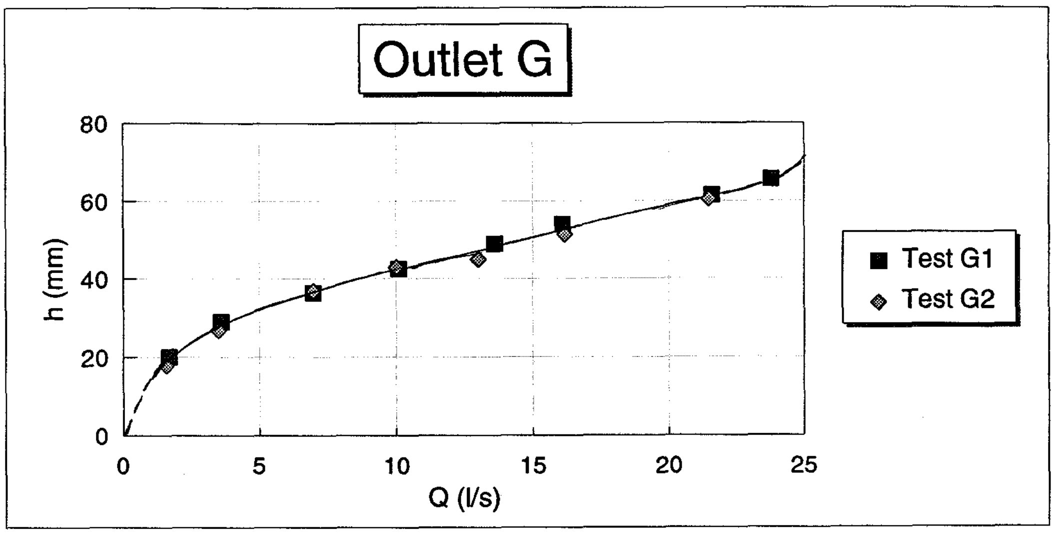


Figure 13 Rating curve of Outlet G

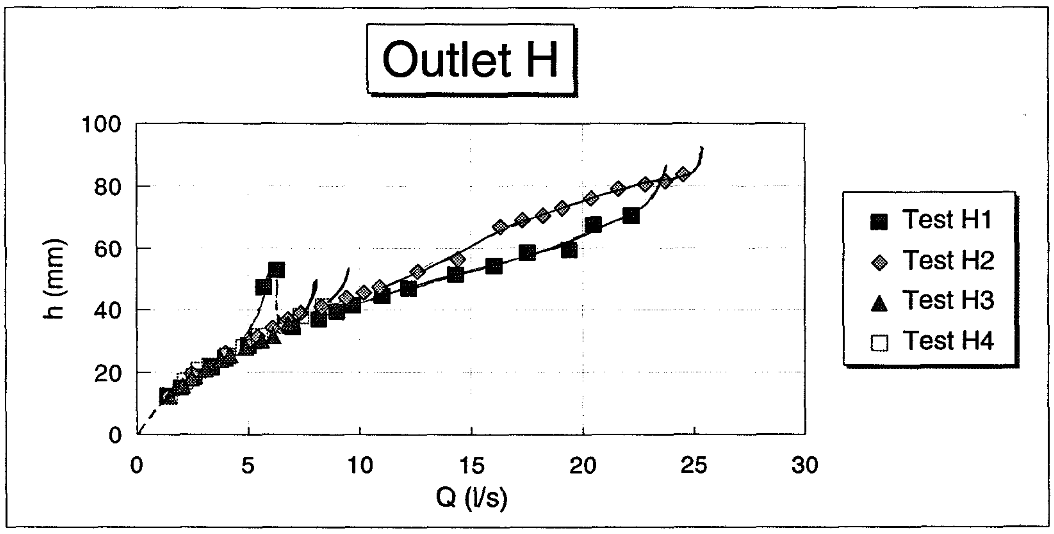


Figure 14 Rating curve of Outlet H

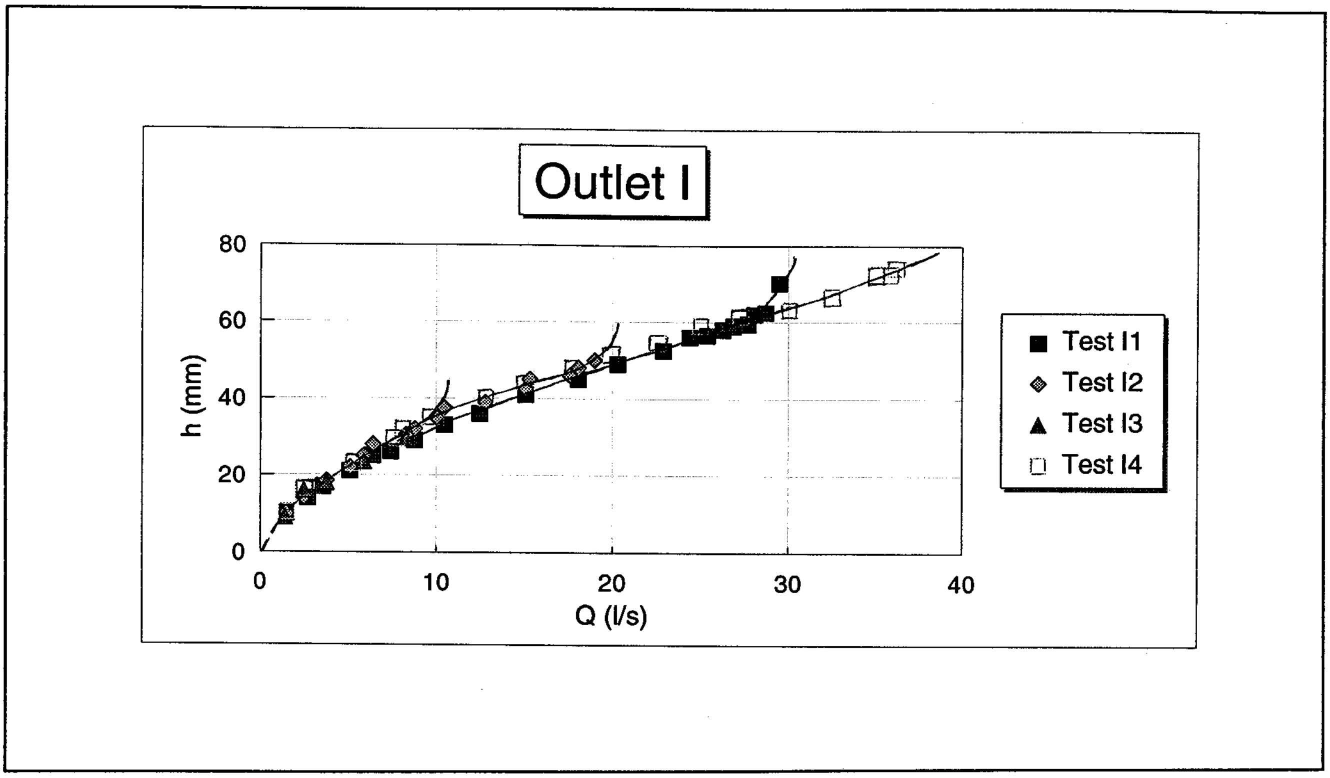


Figure 15 Rating curve of Outlet I

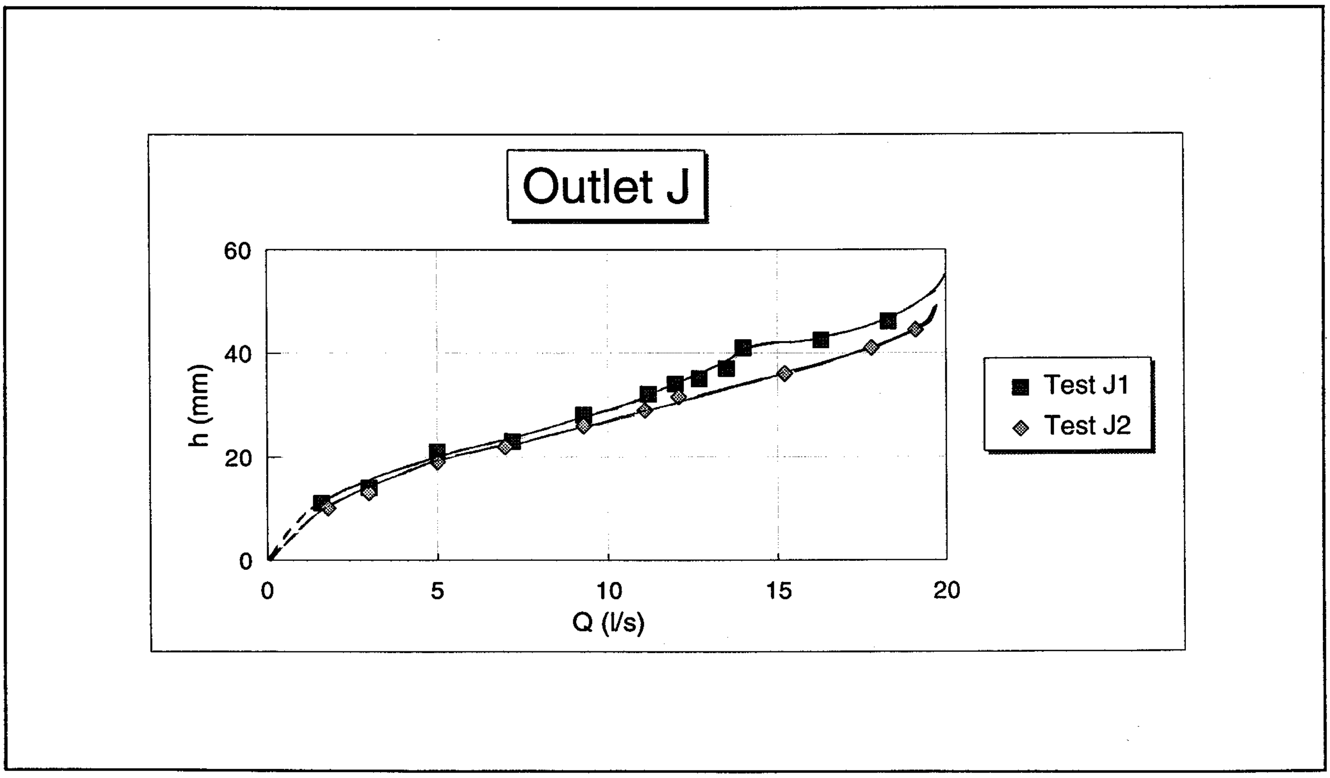


Figure 16 Rating curve of Outlet J

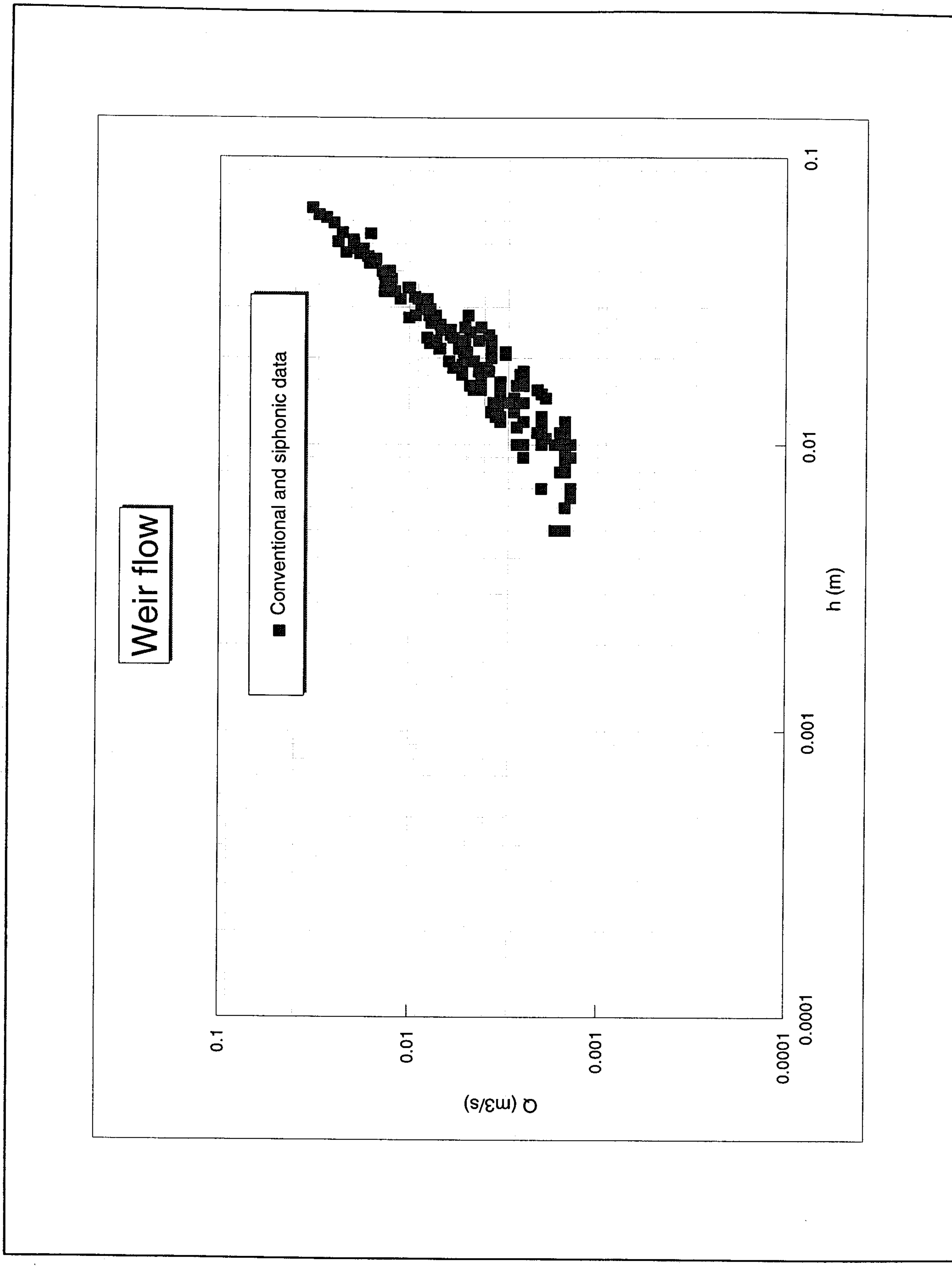


Figure 17 Weir flow data

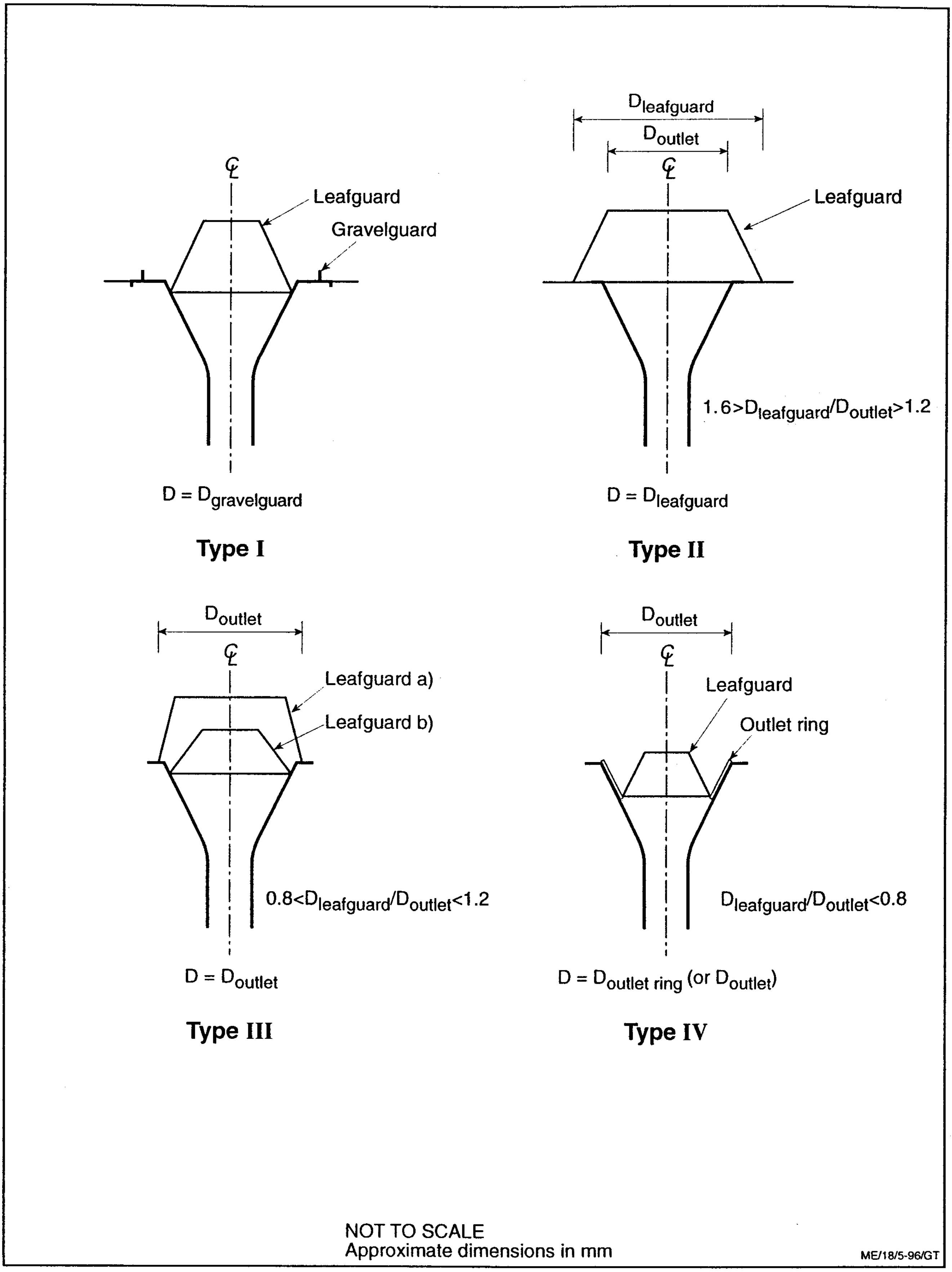


Figure 18 Definition of effective diameter

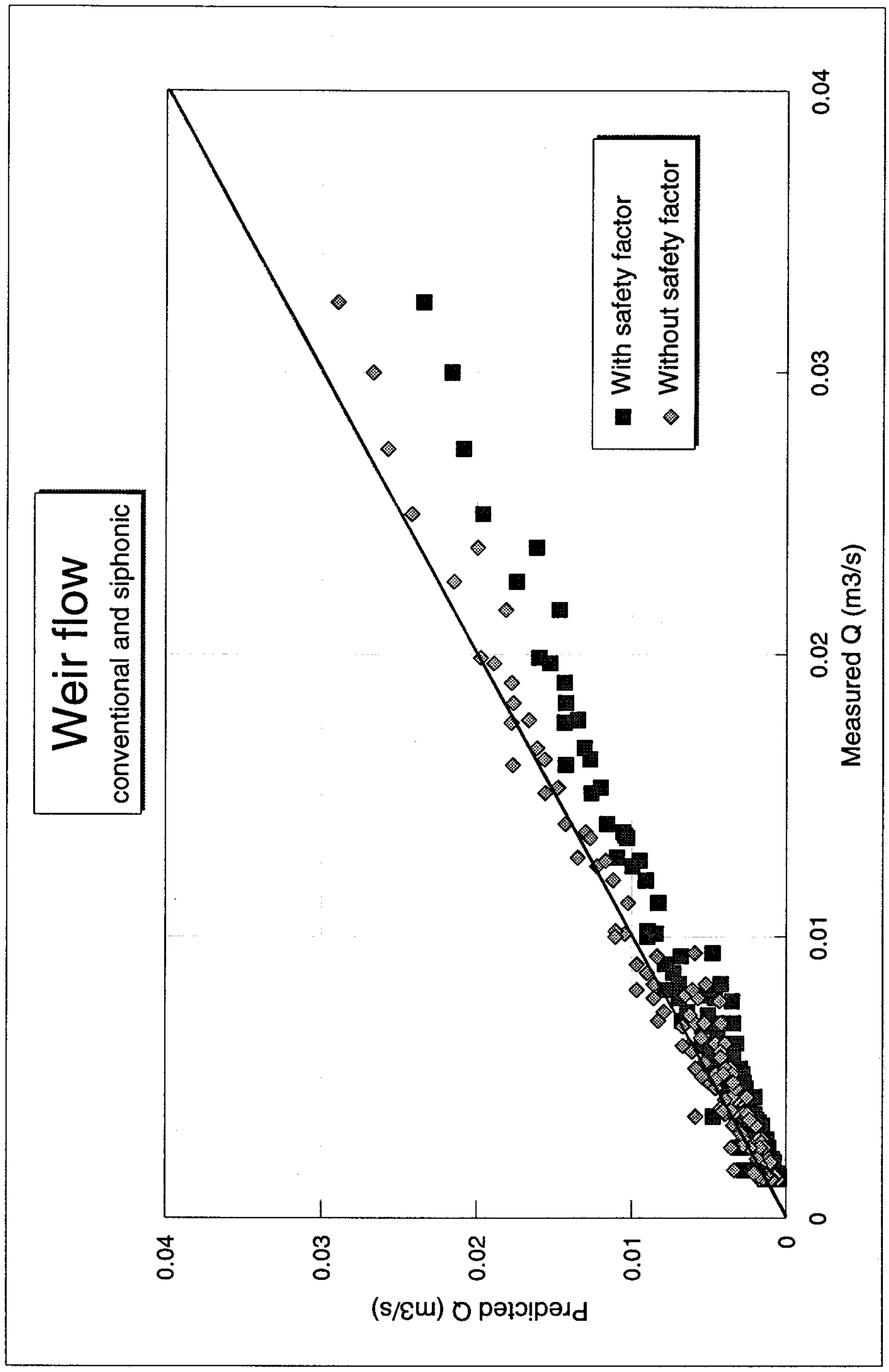


Figure 19 Comparison of measured and predicted flows for weir flow conditions

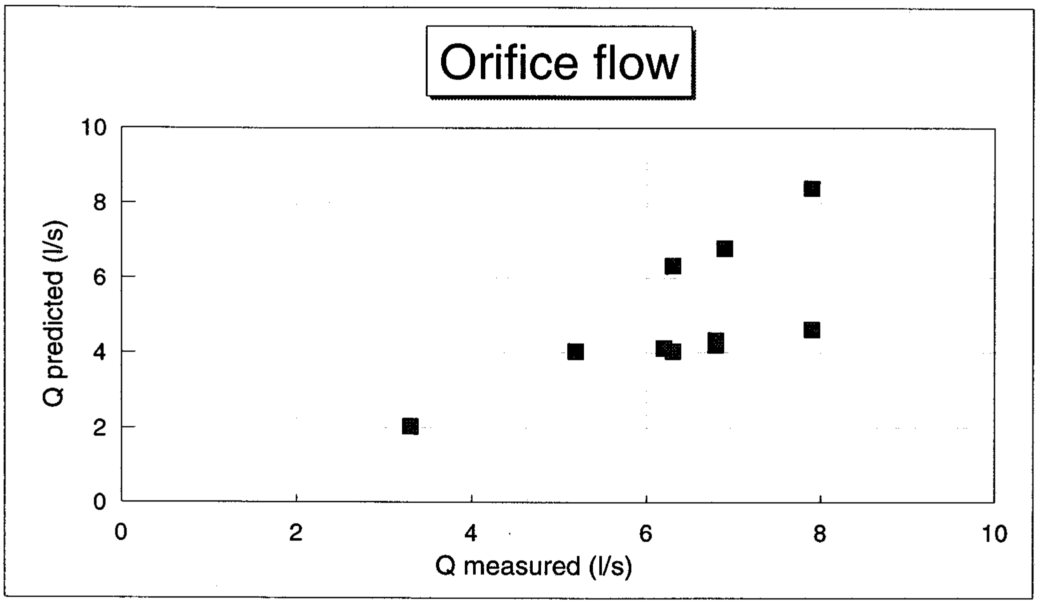


Figure 20 Comparison of measured and predicted flows for orifice flow conditions

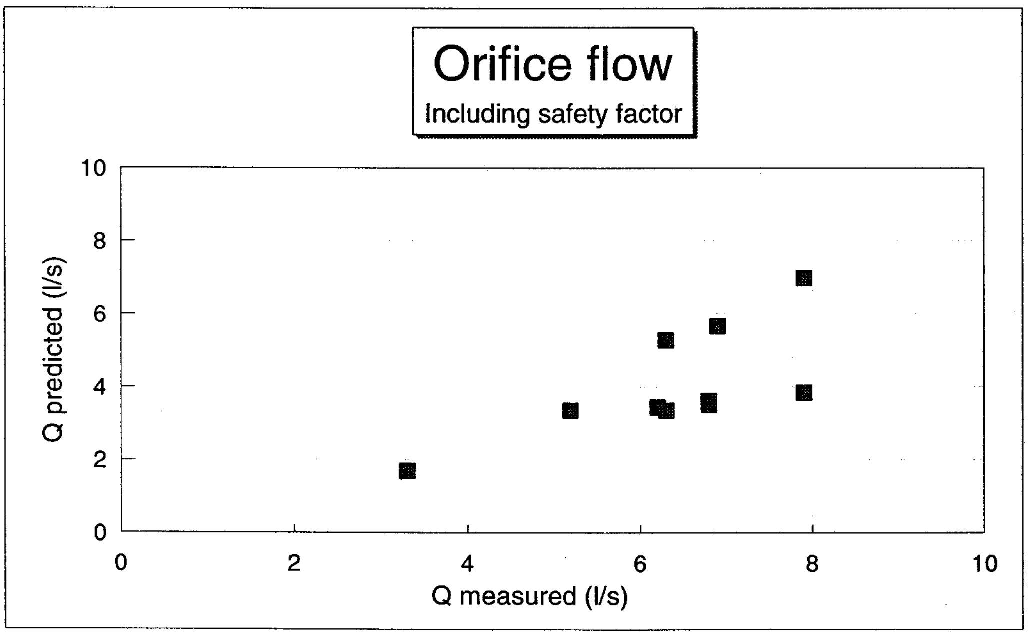


Figure 21 Comparison of measured and predicted flows for orifice flow conditions (inc. safety factor)

Plates

Plate 1   Outlet A (Q = 3 l/s)

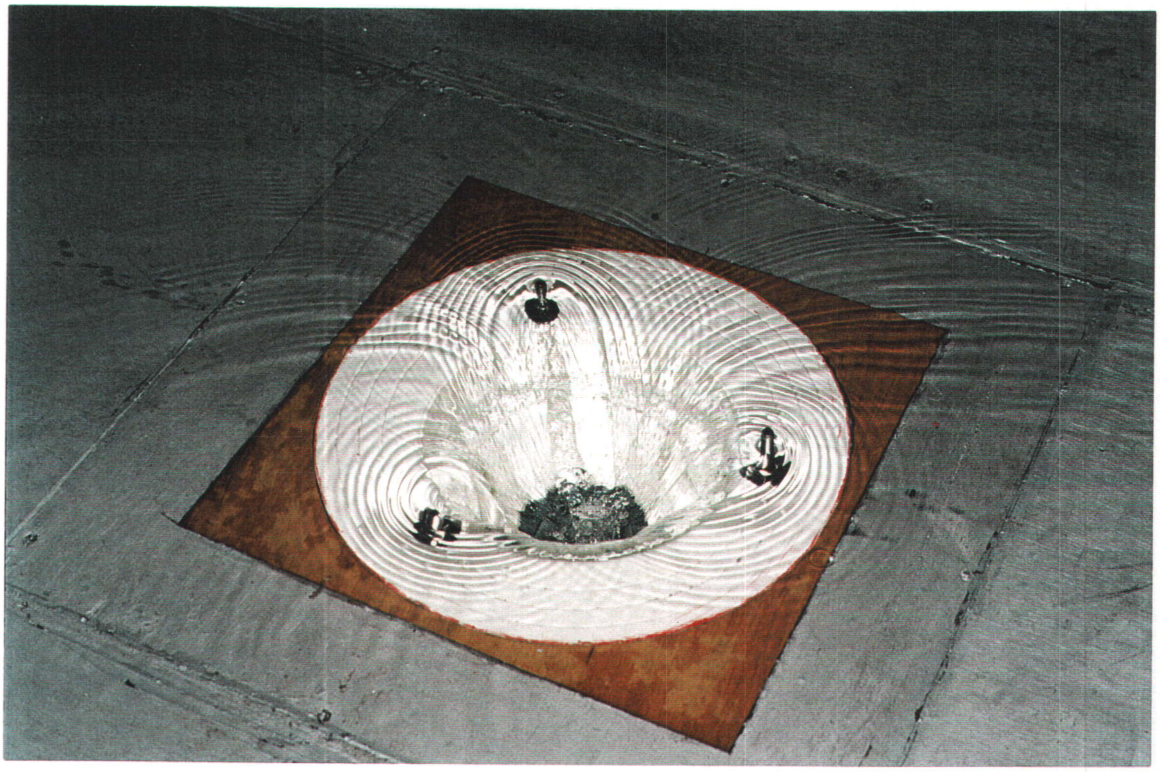


Plate 2   Outlet A without leafguard (Q = 6 l/s)

Plate 3 Outlet B with domed grating (Q = 1.5 l/s)

Plate 4 Outlet B with flat grating (Q = 3.4 l/s)

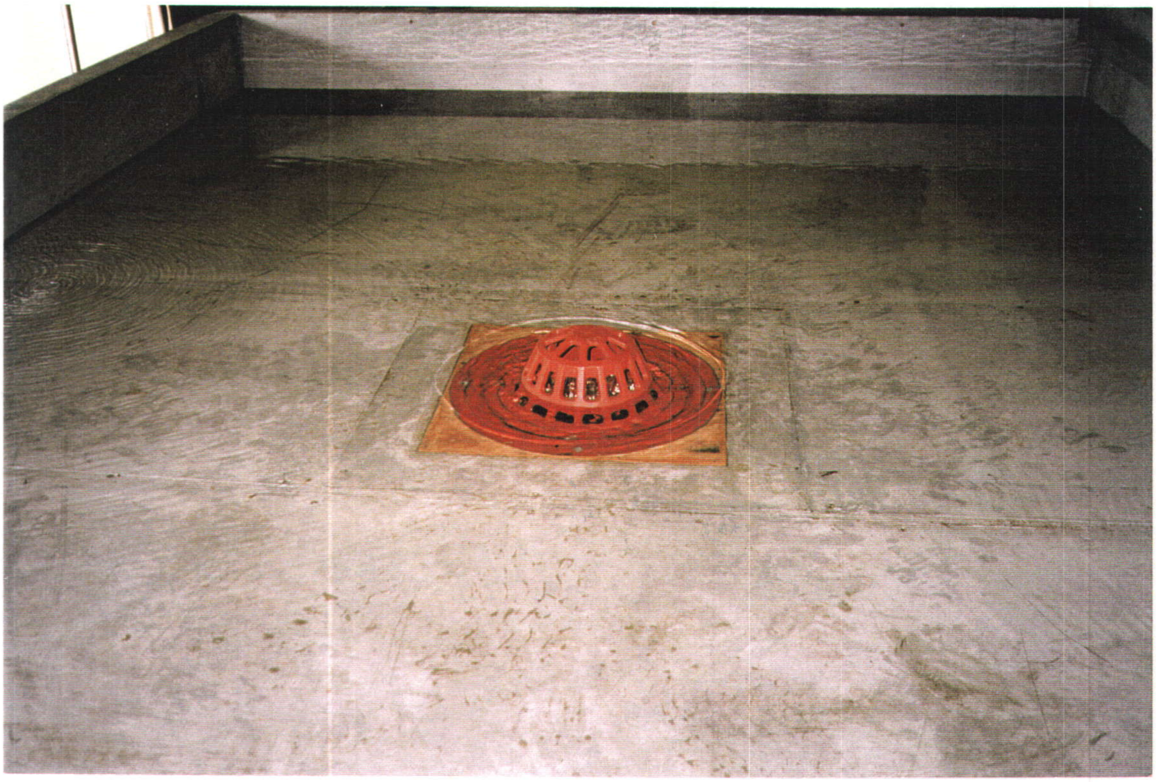


Plate 5 Outlet C (Q = 6.1 l/s)

Plate 6 Outlet D (Q = 2.0 l/s)

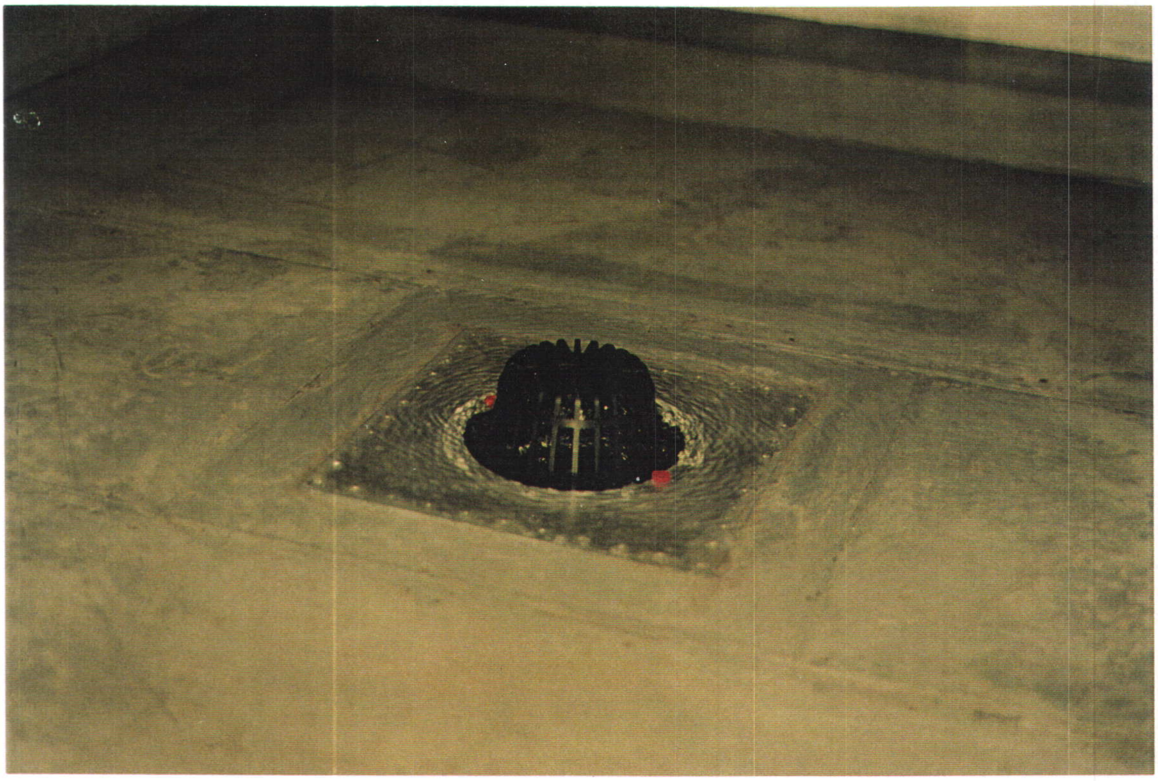


Plate 7 Outlet E (Q = 2.1 l/s)

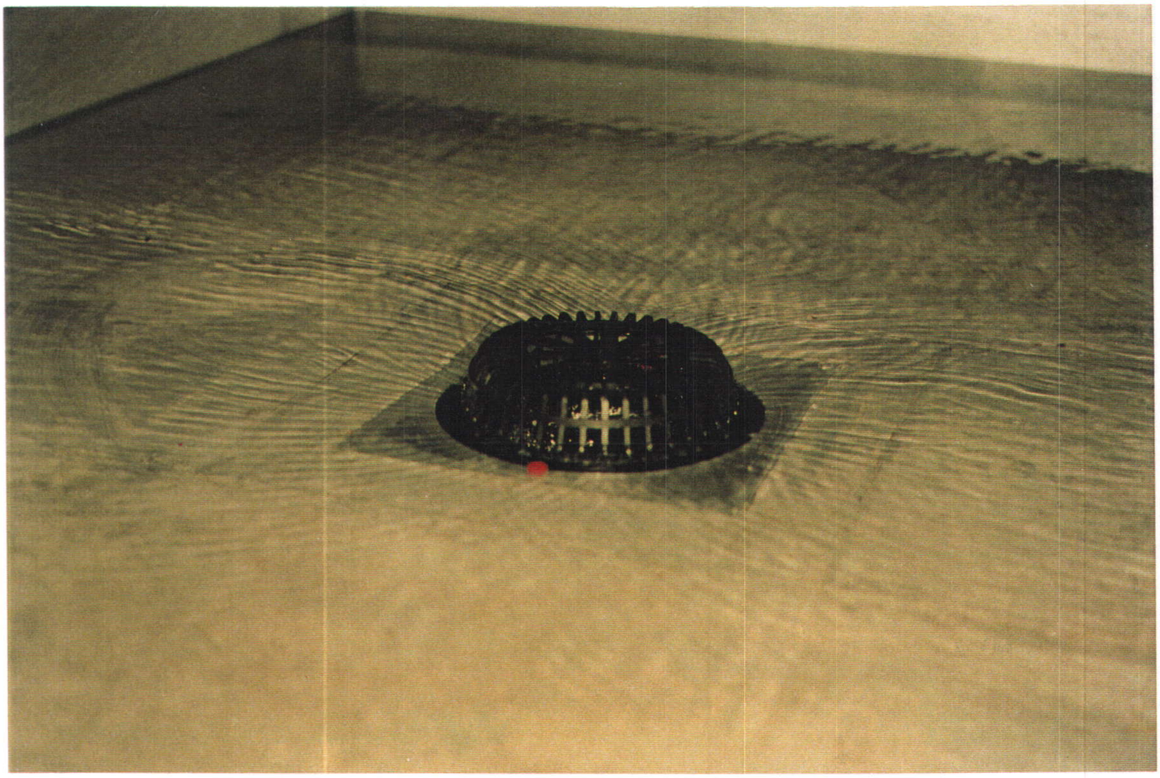


Plate 8 Outlet F (Q = 18.1 l/s)

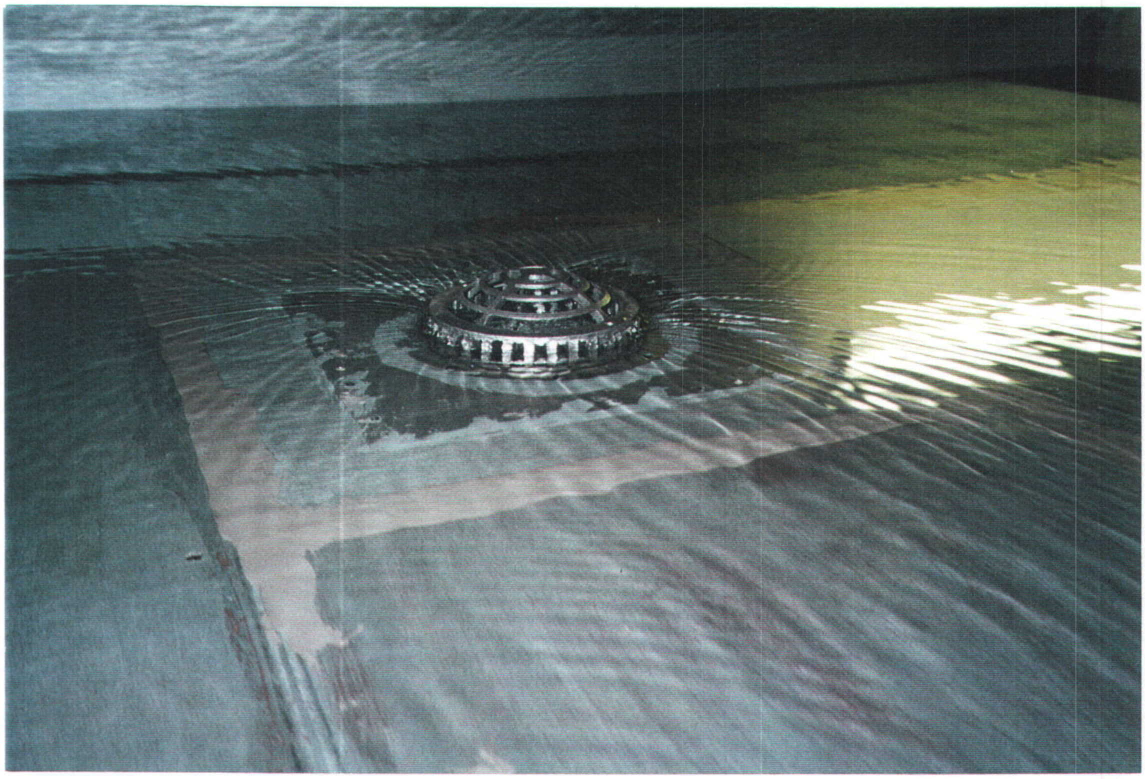


Plate 9 Outlet G

Plate 10 Outlet J (Q = 5 l/s)