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Energy Losses at Manholes
Laboratory measurements at non-stationary flow

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ENERGY LOSSES AT MANHOLES

LABORATORY MEASUREMENTS
AT
NON-STATIONARY FLOW

CONTENTS

SUMMARY

Flow through manholes causes energy losses which may have considerably reducing effects on the capacity of drainage pipe systems. In a previous study at the hydraulics laboratory, Chalmers University of Technology, losses at stationary, surcharged flow were determined. During these tests it was discovered that within a special depth range at straight-through flow, flow patterns were established which multiplied the loss coefficient compared to the normal value at large water depths. As the establishment of these patterns, a combination of lateral surging and horizontal rotation, needed some time it was felt important to make supplementary tests at non-stationary flow. To the author´s knowledge, such tests have not been made earlier.

The non-stationary measurements were made in the same laboratory model as the stationary with some exceptions. Electronic pressure transducers were used instead of open piezometers, a sonic level transmitter was used at the manhole, a direct-reading flow meter was installed at the downstream end of the downstream pipe and all measuring data were recorded by a computer.

The measurements showed that a shift between the special flow pattern described above and the normal pattern needed some 20-30 sec in the model, i.e. 30-45 sec in the prototype. This is a short time compared to the time scale in normal drainage hydrographs but it is interesting to notice that at certain conditions either one of two quite different values of the loss coefficient could represent the flow through the manhole.

To sum up, the study showed that the results from the rather extensive tests at stationary conditions that were made at CTH are valid also for non-stationary flow except for very steep hydrographs.

1. BACKGROUND

Energy losses in flow through manholes have significant effect on the transport capacity in pipe systems especially at surcharged conditions as the losses then are added upstream.

Earlier reports (LINDVALL, 1984 and 1987) show the results of a study at stationary flow made in the hydraulics laboratory at Chalmers University of Technology. The measurements covered the two most frequent flow cases: straight-through flow with and without a 90° lateral. Two different types of manhole design were tested, the difference being the way in which the floor channels joining the connecting pipes in the manhole were made, see Figure 1. In manhole type I the channel depth was half the pipe diameter and the connection of the lateral channel to the main was right-angled and sharp-edged. In type II, the channel depth was equal to the pipe diameter, the lateral channel connection was curved and the edges of both channels were rounded off.

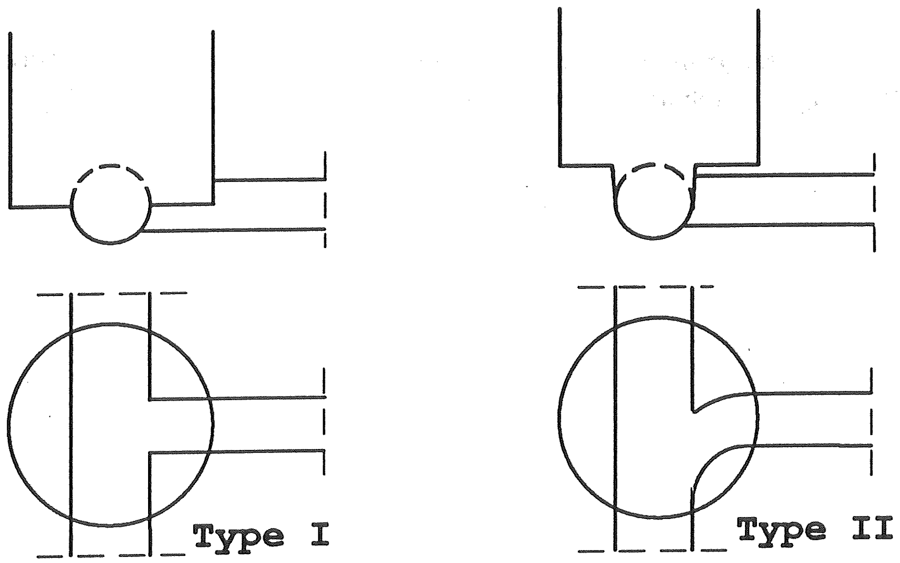


Figure 1. Manhole type I and II.

At the measurements manhole diameter, lateral pipe diameter, water level in the manhole and flow rate were varied. The loss coefficient, KH, is defined as (see Figure 5)

$$KH = \frac{2g}{v^2}\Delta H$$

where ΔH is the vertical distance between the grade lines extrapolated to the manhole centre

v is the flow velocity in the downstream pipe

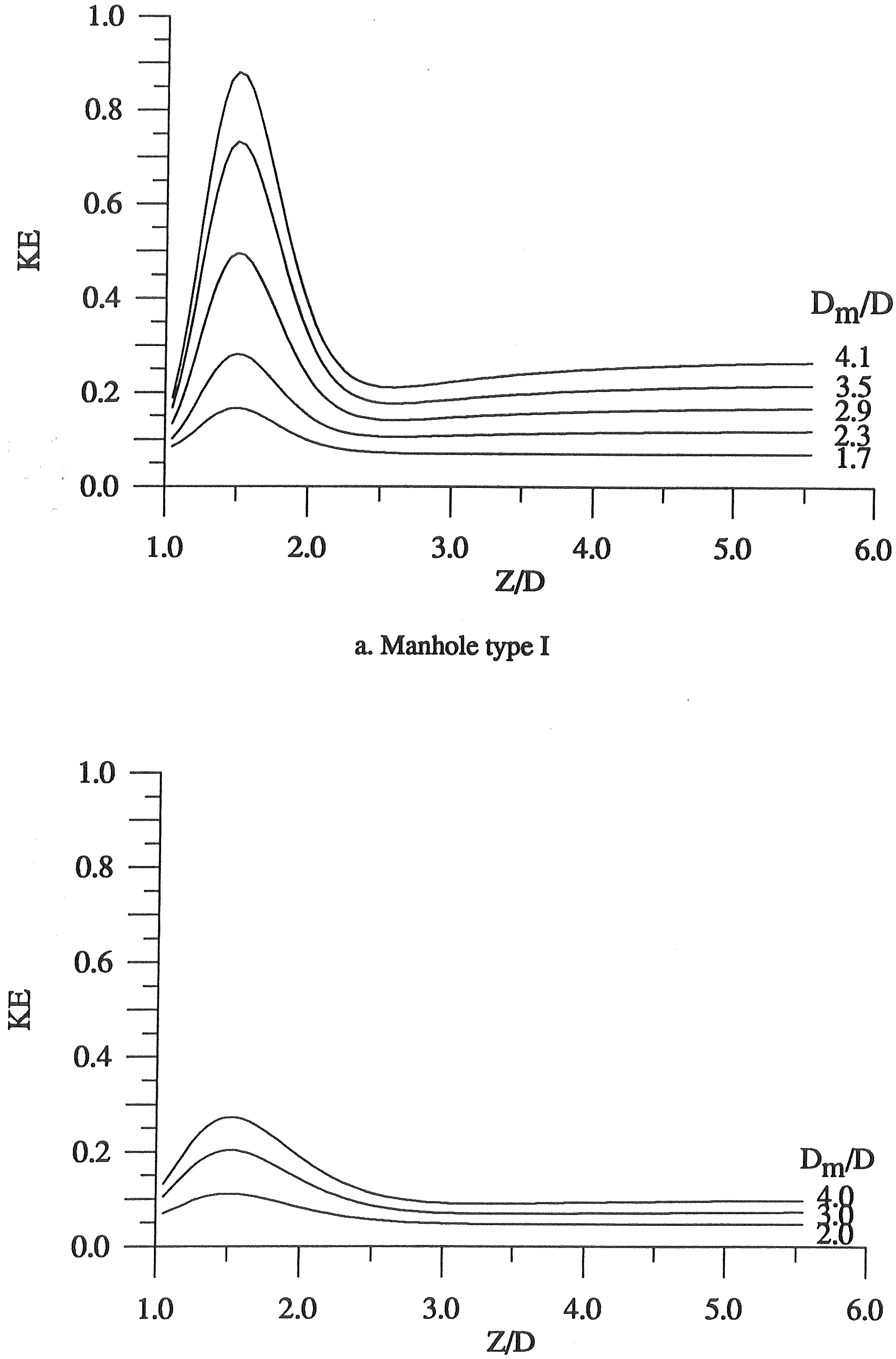
To be precise, KH is the pressure difference coefficient, only equal to the energy loss coefficient, KE, at straight-through flow and when the velocity in the upstream and the downstream pipe is the same, as in Figure 2 and 3 below.

The flow of water through a discontinuity like a manhole creates several flow patterns depending on manhole shape, water depth, flow velocity and flow ratio. Besides turbulence from expansion and contraction there are rotations and surges in different directions. Each flow pattern results in one value of the loss coefficient. At the stationary measurements at straight-through flow one consistent phenomenon was observed. In the depth range 1.0D-2.3D, D being the diameter in both upstream and downstream pipe, there was a significant increase in the energy loss coefficient, more pronounced for the manhole type I than for type II and increasing with the manhole diameter/pipe diameter ratio, see Figure 2.

Similar results can be deduced from raw data published from other laboratories (LIEBMANN, 1970 and ARCHER et al., 1978), although the reports do not present the same conclusions, see Figure 3.

All the measurements described above were made under strictly stationary flow conditions. The readings at Chalmers were made 10-15 min after the change of flow or water level in order to give enough time for the "representative" flow pattern in the manhole and corresponding pressure levels to be established. Strictly stationary conditions do not exist in the prototype and it was felt important to check how a time variation of flow and level affects the flow pattern. To the author`s knowledge, such a study has not been made earlier. The straight-through flow case in a manhole type I was chosen because the variation of the coefficient was fairly large and regular.

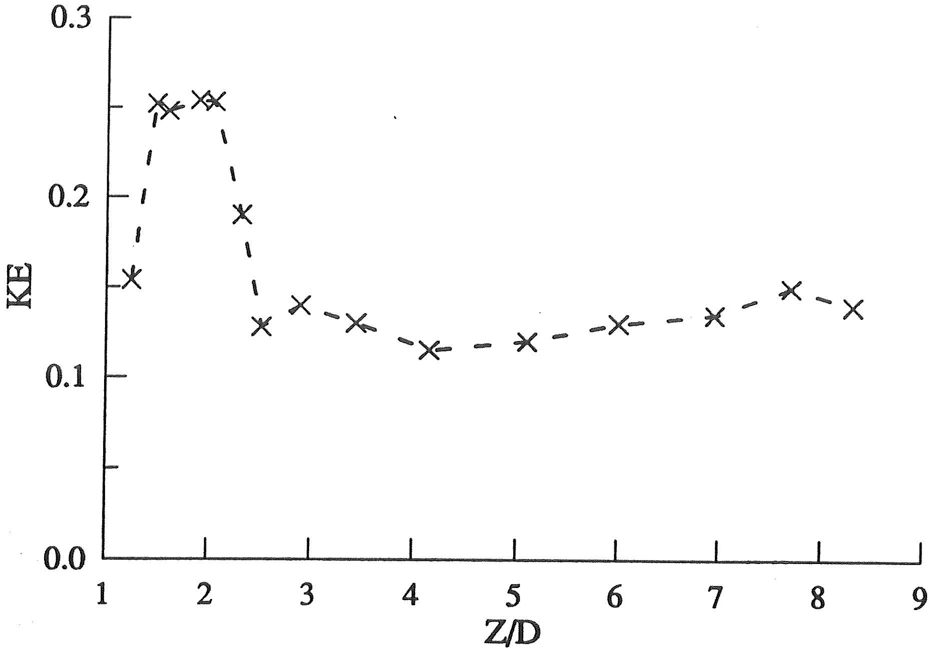
This report consequently presents the results of measurements at non-stationary conditions in straight-through, surcharged flow in a manhole.



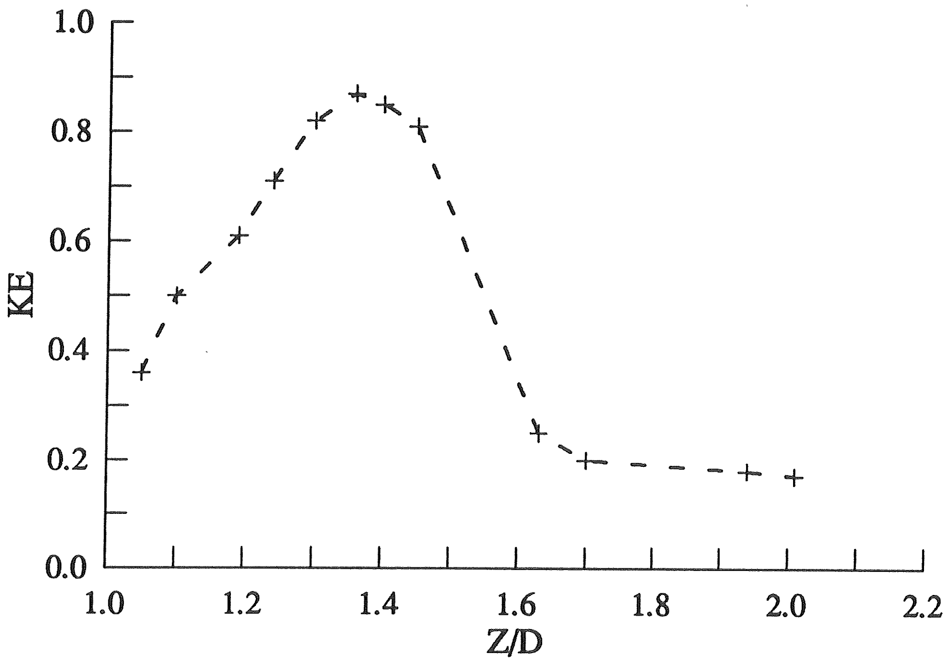
a. Manhole type I

b. Manhole type II

Figure 2. Energy loss coefficient, KE, versus depth, Z/D, and manhole diameter, D_m/D, for straight-through flow. Laboratory tests at CTH at stationary conditions.



a. ARCHER et al. Manhole type II.



b. LIEBMANN. Manhole type I

Figure 3. Energy loss coefficient, KE, versus water depth, Z/D, deduced from raw data published by a. ARCHER et al. and b. LIEBMANN.

2. LABORATORY MODEL FOR NON-STATIONARY TESTS.

The measurements were made in the same model as those made at stationary conditions, see Figure 4. The pipe diameter was 0.144 m and the pipe length upstream and downstream the manhole was 12.0 and 16.5 m respectively. The downstream reservoir was equipped with a movable weir for adjustment of the water level at the manhole. Both the weir and the regulating valve were handled manually.

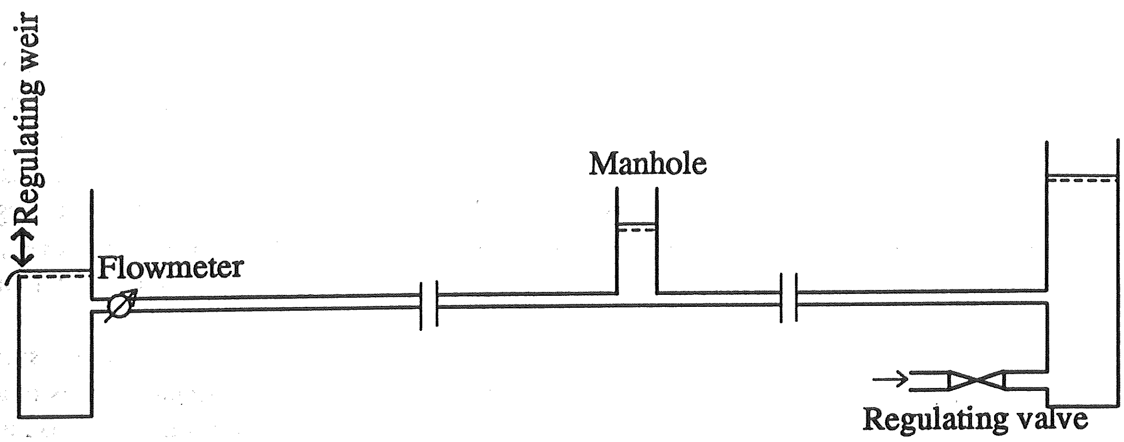


Figure 4. Test rig.

The measuring technique had to be adjusted for non-stationary conditions. A direct reading, electromagnetic type flow meter was installed at the downstream part. Pressure transducers were installed at pressure taps in the upstream pipe at 2.00 m and 12.00 m from the centre of the manhole and in the downstream pipe at 2.00 m and 10.00 m. From these readings the pressure drop at the manhole centre was evaluated. The transducers were calibrated against tube manometers at stationary conditions before each measuring session and the resulting accuracy was about the same as for the measurements at stationary conditions. The measurements of the water level in the manhole were made with a sonar level meter. The time constant was set to 3 sec. The accuracy was not as good as for the pressure transducers but still acceptable considering the sometimes rather disturbed water surface in the manhole. The collection of data was made with a personal computer.

3. MEASUREMENTS

The measurements described in this report were made on a manhole type I with the diameter 3.6 times the pipe diameter, i. e. roughly corresponding to a Ø300 mm pipe through a Ø1000 mm manhole, for which the measurements at stationary flow showed a large variation with water depth of the loss coefficient. There was no connection of a lateral pipe.

The easiest way to initiate a water level variation in the manhole was to use the movable weir at the downstream reservoir. To get the same variation by increasing or decreasing the flow was not possible because of the limited length of the downstream pipe and also because of the fact that the relative error in the evaluation of the loss coefficient increases at decreasing flow. The disadvantage of using this method is of course that unrealistic flow situations were created: water levels were going down at increasing flow and viceversa. It is not likely however that this had any effect because the flow pattern in the manhole and the corresponding loss should depend only on the difference of the flow into the manhole and out of it, regardless of whether the change is coming from the upstream or the downstream pipe. However, a few measurements were made where the flow was regulated to be in phase with the level variation.

Characteristic for the specific flow patterns which cause the heavy increase of the losses in the certain depth range is rather high velocities along the wall. The model manhole was made of PVC, i.e. a hydraulically smooth surface. Measurements were therefore also made on a manhole with increased roughness, the resulting roughness maybe somewhat higher than if scaled exactly.

It is assumed in this report that the studied flow phenomena are scaled according to Froude modelling, as inertia and gravity are the dominant forces. The length scale was 1:2 and hence the time scale was 1:1.4.

The pressure difference ΔH is defined as the vertical distance between the pressure grade lines extrapolated to the manhole centre, see Figure 5.

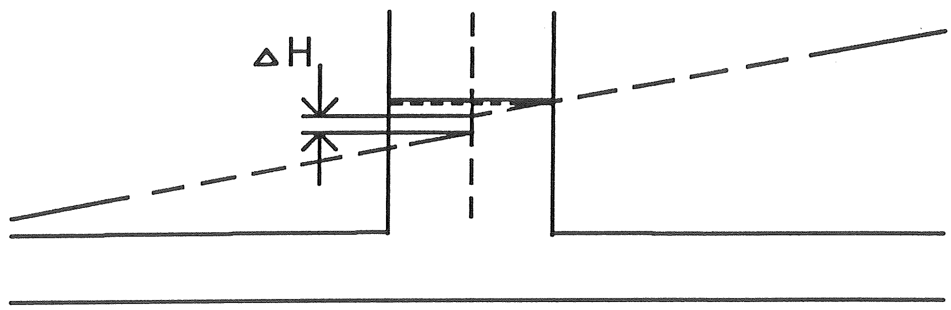


Figure 5. Definition of ΔH.

The pressure difference coefficient KH is defined as

$KH = 2g(A / Q)^2 \Delta H$ where Q is the flow and A is the area in the downstream pipe.

It is only at stationary flow and when the pipe diameter is the same upstream and downstream of the manhole that the energy loss is the same as the pressure difference. The energy loss coefficient, KE, is the adequate parameter to use in this study for comparison between stationary and non-stationary flow. The pipe diameter being the same, the energy loss coefficient KE is related to KH according to

$KE = KH + (Q_u / Q)^2 - 1$ where Q_u is the flow in the upstream pipe

Q_u was calculated as the sum of Q and the storage per time unit in the manhole. In the evaluation the average storage in two seconds was used.

During the measurements all transducers were scanned five times per second. At the evaluation the raw data was filtered with a running average of 15 readings, i.e. three seconds.

4. RESULTS

4.1 Effects of the change rate of the water level.

The purpose of the measurements was to find out the time needed to switch from one flow pattern to another associated with significantly different energy loss and to show the consequences of the delay.

Figure 6a shows a test where the water level in the manhole (dotted line) at first increases from slightly above the pipe crown to about 2D above the crown in 80 sec and then decreases at about the same rate to the original level. The flow in the downstream pipe is shown as a dashed line. The calculated values of the loss coefficient, KE, are plotted as a function of time.

If KE instead is plotted as a function of water depth in the manhole, Z/D, the result is given in Figure 6b, where the course of the test is shown with arrows. As a comparison the mean curve for the stationary measurements is shown (dotted line). One can see that the flow pattern connected with high losses is immediately established and remains until the water depth is about 2.3D, i.e. considerably longer than it would have been at stationary conditions. At Z > 2.5D the flow pattern is the normal with low losses. This flow pattern remains when the water depth again is lowered to switch just at the water depth Z = 1.2D. The result is thus that the loss coefficient can assume two different values for the same water depth.

If the same water level variations are done at about half the regulating speed the result is in accordance with Figure 7a and 7b, where it can be seen that the change of pattern is closer to those at stationary conditions.

Figure 8a and 8b show tests in reverse order, i.e. where the start is at a large water depth and a normal flow pattern. When reducing the water depth to 1.2D and then increasing to 2.5D roughly the same result as in Figure 6b is obtained. Tests with half the regulating speed, Figure 9a and 9b, give similar results as in Figure 7b.

The tests show accordingly that it takes some time to change the flow pattern in the manhole and the effect is that the loss coefficient can assume two quite different values within the specific depth range. The size of this depth range depends on the change rate of the variation, i.e. the steepness of the hydrograph. The exact time for the change is difficult to evaluate from our tests because also for stationary flow conditions there is a transition depth zone between high and low losses. The delay seems to be of the order 20-30 sec, which with the assumption of Froude modelling, should mean 30-45 sec in the prototype.

4.2. Effects of regulation of flow versus water level.

The easiest way to produce a water level change in the manhole was of course to operate the weir at the downstream end. This created however a somewhat unrealistic relation between flow- and level variations: the normal is that they increase and decrease at the same time, here the result is the opposite. Figure 10 shows a measurement where the upstream flow was regulated in phase with the regulation of the downstream weir. The result should be compared with the measurement in Figure 7 and apparently there are no significant differences.

4.3. Effects of the wall roughness in the manhole.

The model pipes and manhole were made of PVC which means that the flow was hydraulically smooth which is not the case in the prototype. Because the flow patterns that give the increased head losses in the manhole are characterised by higher flow velocities at the wall, friction should have some effect. Additional tests were therefore made with artificially increased wall roughness in the manhole. It was achieved by gluing sand to the wall and the result was judged to give slightly larger roughness than if properly scaled. Figure 11 shows a typical result and should be compared with Figure 6. Friction reduces or eliminates the time needed to change from a high loss flow pattern to a low loss pattern at larger depth but delays the change back when the water depth is again going down.

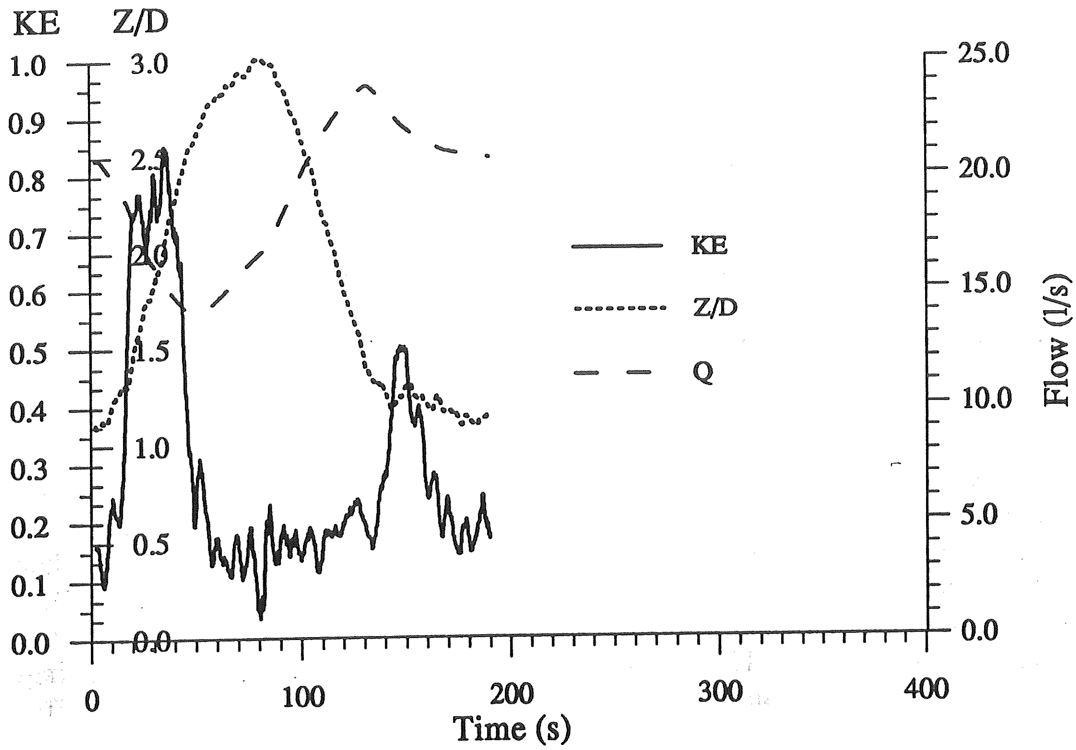


Figure 6a. Measurement with start at low water level - increase to 3.0D - decrease to 1.0D.

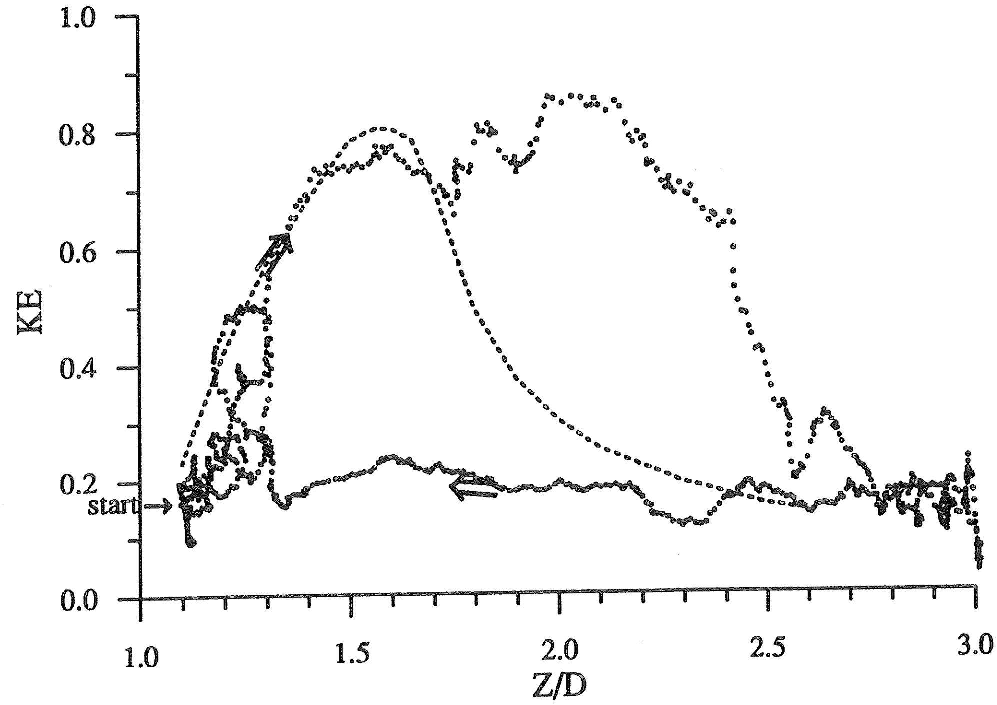


Figure 6b. Energy loss coefficient, KE, as a function of relative depth, Z/D, for the test shown in Figure 6a. The mean values from the stationary measurements are shown as a dotted line.

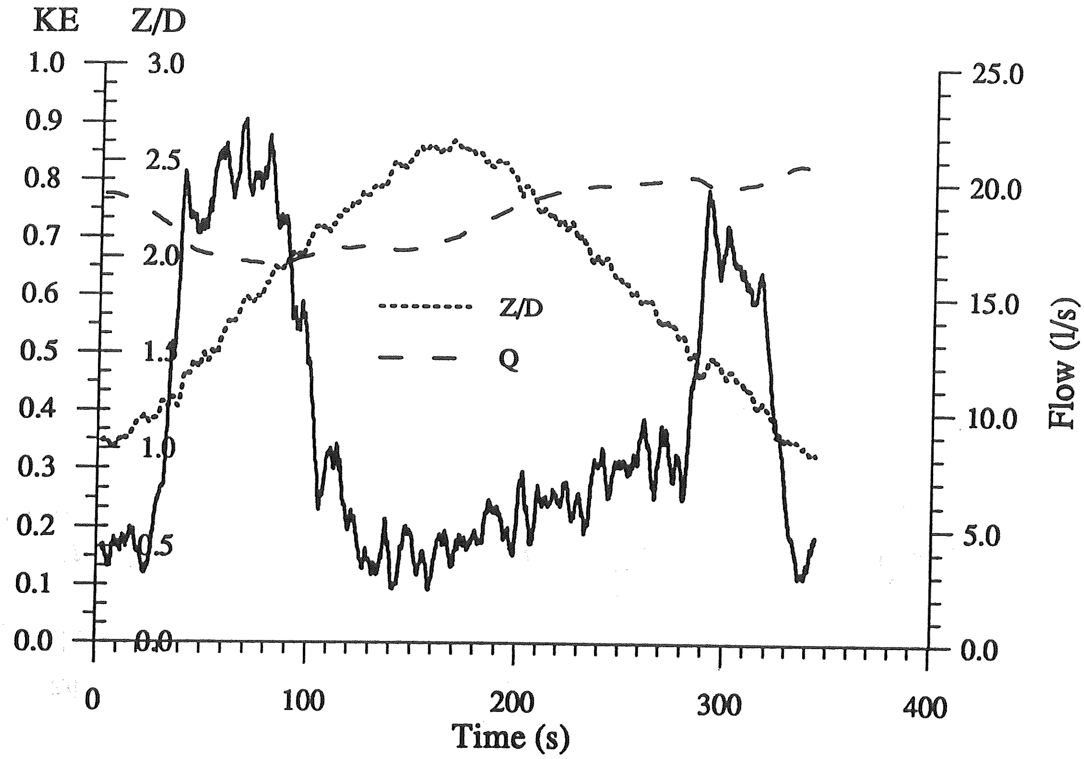


Figure 7a. Same measurement as in fig. 6, but with half the regulating speed.

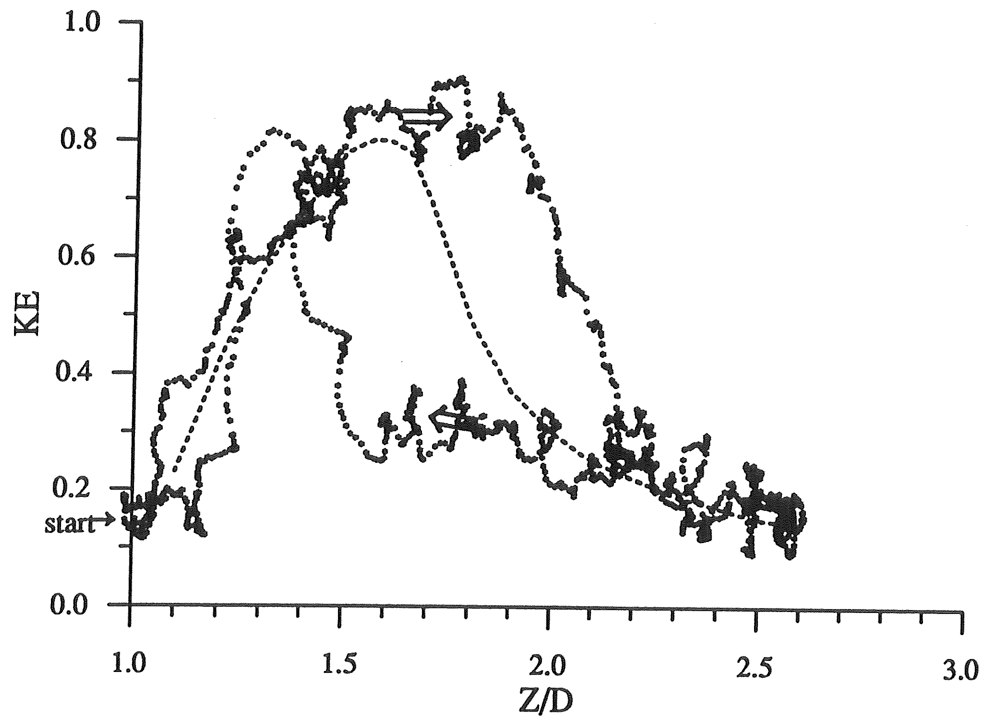


Figure 7b. Energy loss coefficient, KE, as a function of relative depth, Z/D, for the test shown in Figure 7a. The mean values from the stationary measurements are shown as a dotted line.

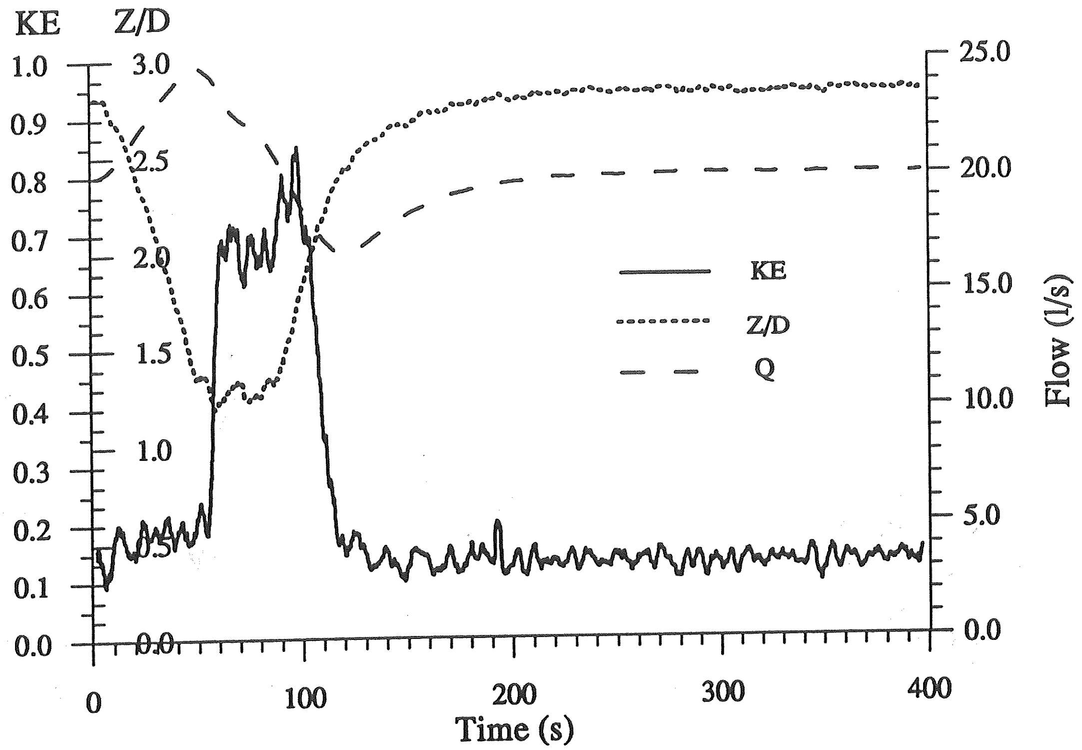


Figure 8a. A measurement with start at large water depth - decrease to 1.2D - increase to 2.8D, with the same regulation speed as in Figure 6.

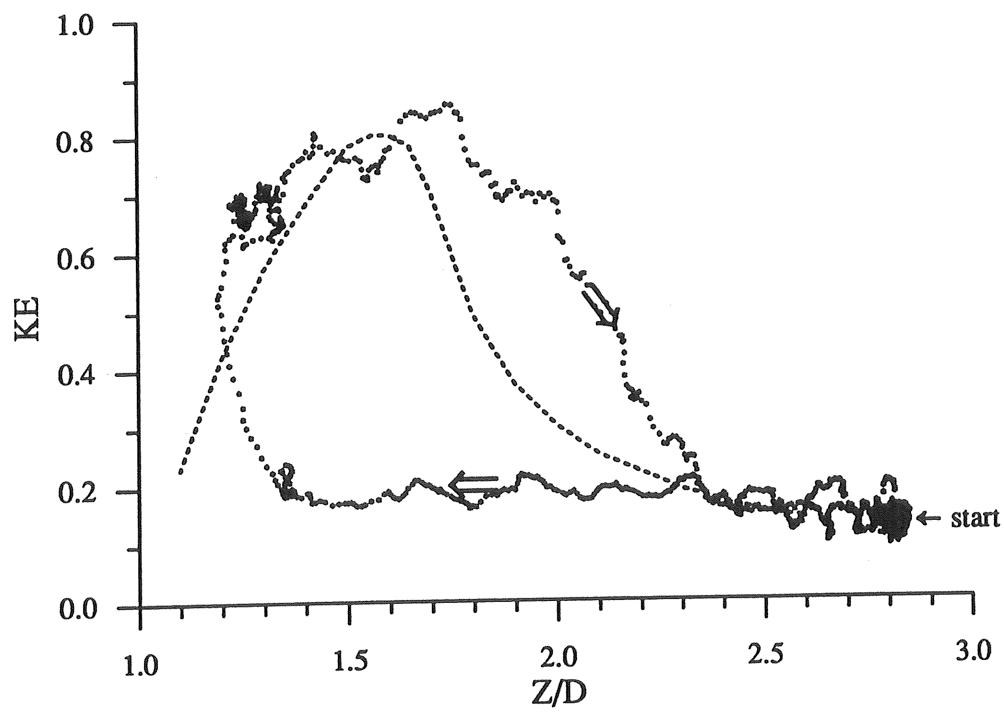


Figure 8b. Energy loss coefficient, KE, as a function of relative depth, Z/D, for the test shown in Figure 8a. The mean values from the stationary measurements are shown as a dotted line.

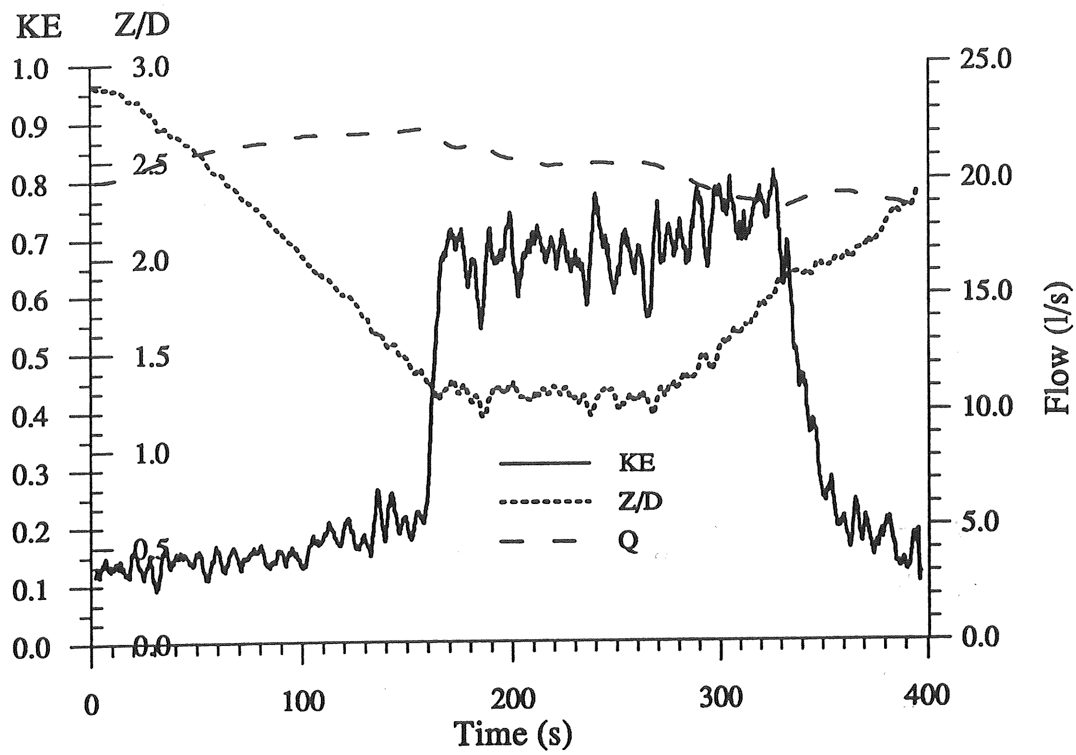


Figure 9a. Same measurement as in Figure 8 but with half the regulating speed.

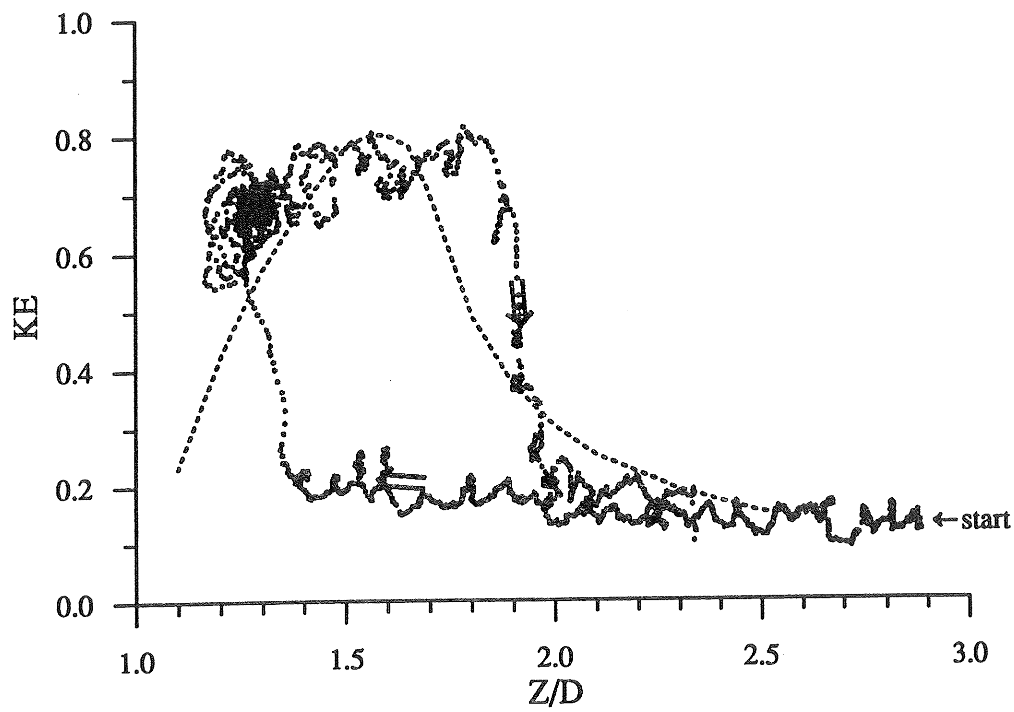


Figure 9b. Energy loss coefficient, KE, as a function of relative depth, Z/D, for the test shown in Figure 9a. The mean values from the stationary measurements are shown as a dotted line.

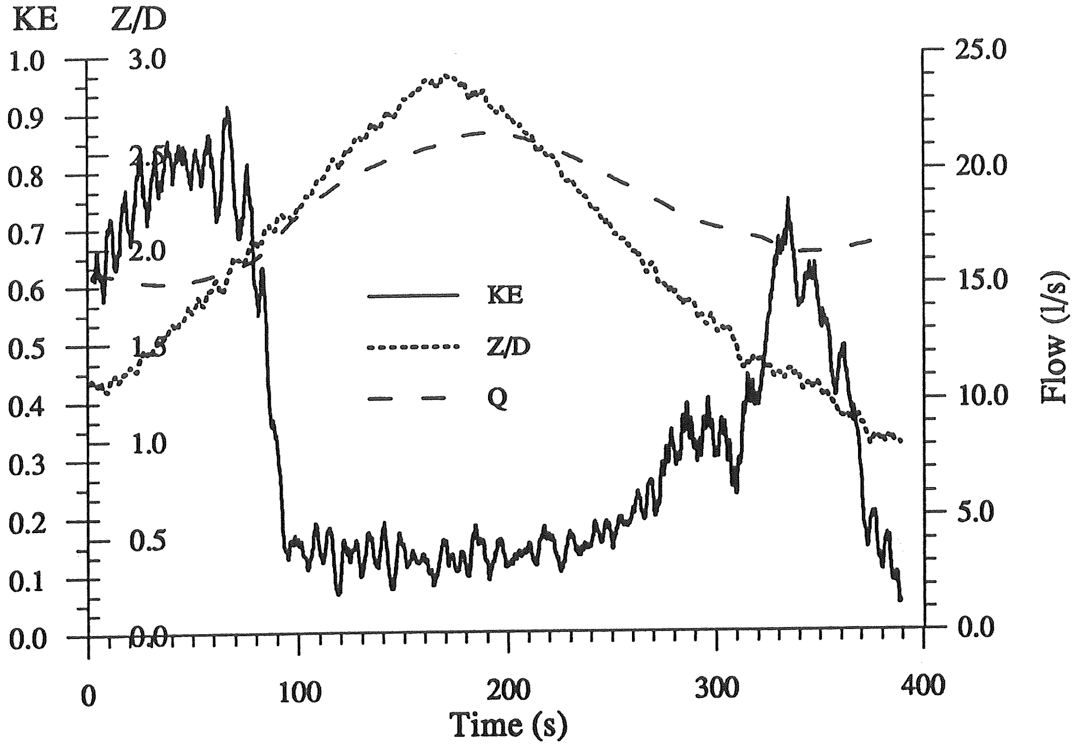


Figure 10a. Simultaneous regulation of flow and level.

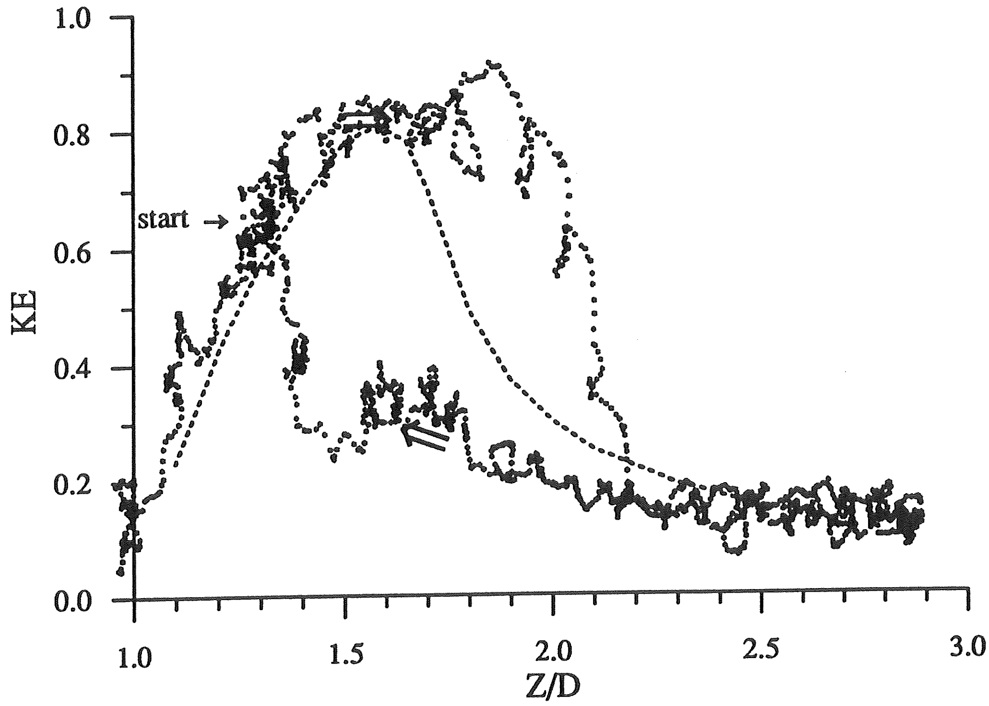


Figure 10b. Energy loss coefficient, KE, as a function of relative depth, Z/D, for the test shown in Figure 10a. The mean values from the stationary measurements are shown as a dotted line.

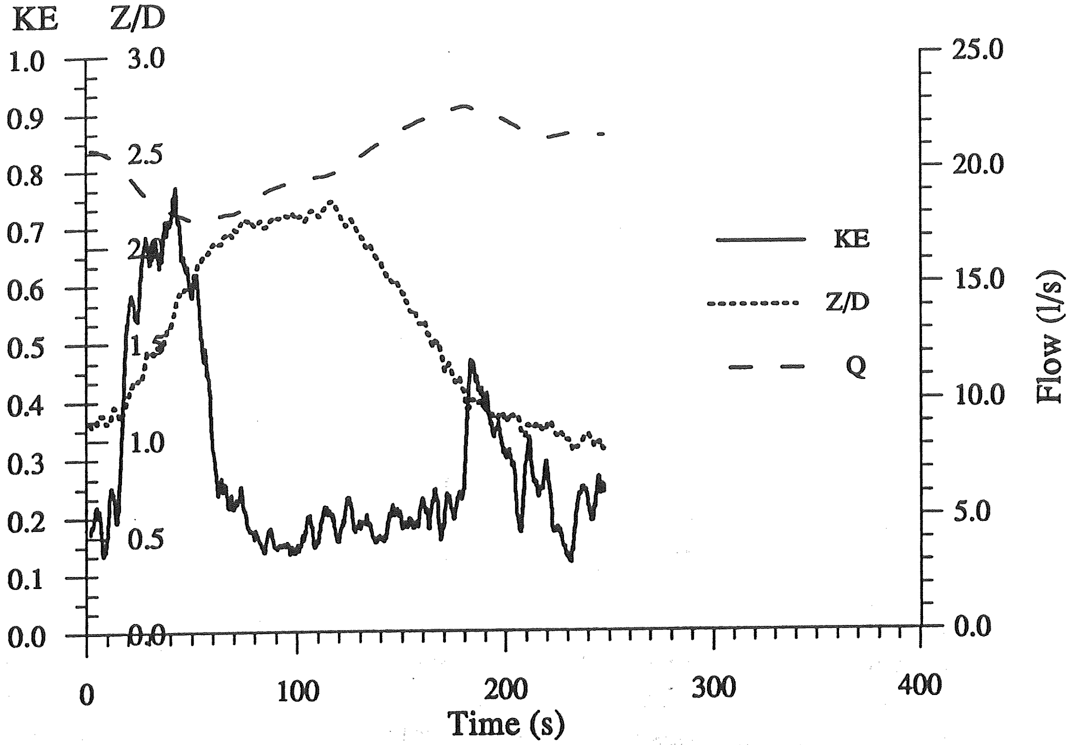


Figure 11a. Measurement with increased roughness.

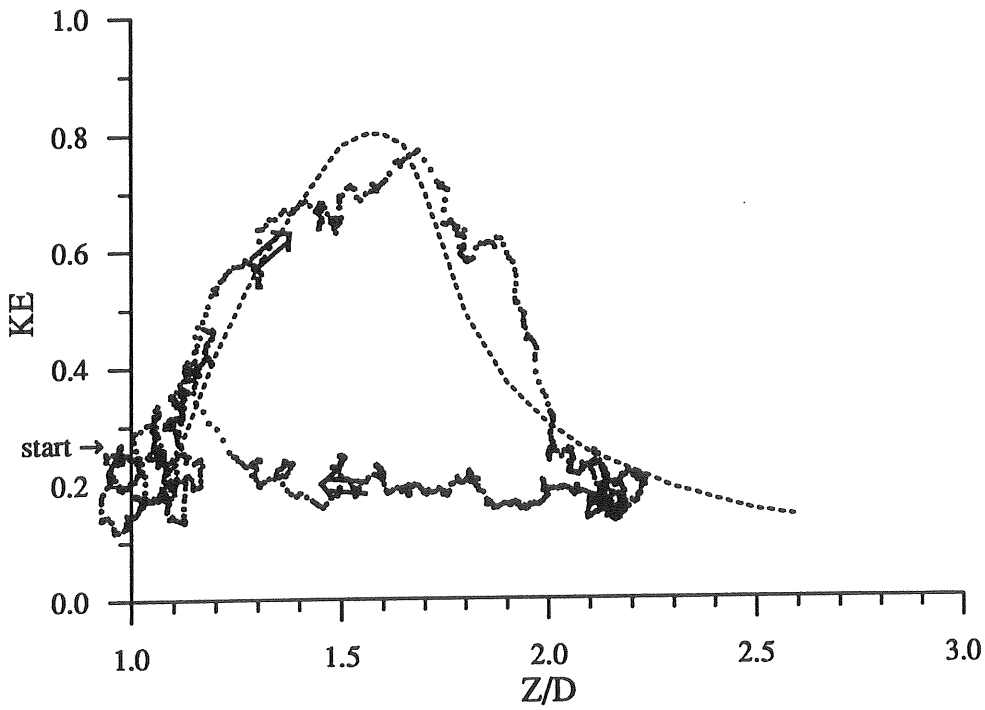


Figure 11b. Energy loss coefficient, KE, as a function of relative depth, Z/D, for the test shown in Figure 11a. The mean values from the stationary measurements are shown as a dotted line.

5. CONCLUSIONS

At surcharged, straight-through flow in a manhole such a flow pattern arises in a certain depth range, 1.1-2.3 times the pipe diameter, that the loss coefficient is multiplied. This study was made in order to find out the time needed to switch to and from such a flow situation and to show the consequences of the delay.

It is not possible to evaluate a precise figure of the delay time, because even at stationary flow there is a transition depth zone between the two different flow patterns, but it has been estimated to 20-30 sec. Assuming Froude modelling the corresponding time in the prototype would be 30-45 sec, i.e. a relatively short time compared to normal hydrographs.

According to the tests at stationary conditions other "abnormal" flow patterns than those examined in this study have considerably less effect on the energy losses. Logically, also the time needed for switching to and from these patterns should be less. *The conclusion must be that the results from the rather extensive tests at stationary flow are valid also for non-stationary flow except for very steep hydrographs.*

The delay in the shift between the two flow patterns leads to that the loss coefficient can take two different values at the same water depth in the manhole. In a surcharged runoff system the pressure variations are much faster than in partly filled pipes and the flow becomes unstable when the loss coefficient varies with the water depth in the manholes (comparable with air suction and release in manholes at a water depth close to the pipe crest). If the delay at an increase of the losses is greater than the delay at a decrease, as the tests with increased roughness show, the instability is reduced.

REFERENCES

ARCHER, B., BETTES, F., COLYER, P.,J., 1978:Head losses and air entrainment at surcharged manholes. Report No. IT 185, Hydraulics Research Station, Wallingford, England.

LIEBMANN, H., 1970: Der Einfluss von Einsteigschächten auf den Abflussvorgang in Abwasserkanälen. Wasser und Abwasser in Forschung und Praxis. Erich Schmidt Verlag.

LINDVALL, G., 1984: Head losses at surcharged manholes with a main pipe and a 90° lateral. Proc. of the Third International Conference on Urban Storm Drainage, Göteborg, Sweden.

LINDVALL, G., 1987: Head losses at surcharged manholes. Proc. of Technical Session D XXII Congress, International Association for Hydraulic Research.