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HYDRAULIC PERFORMANCE OF CONFLICT MANHOLES

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HYDRAULIC PERFORMANCE OF CONFLICT MANHOLES

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16. Abstract

This report details a performance analysis of conflict junction boxes, employed when stormwater lines intersect utility conduits. A variety of configurations currently used by FDOT were tested and rated for turbulent loss characteristics. Special consideration was given to vertical position of the conflict relative to the storm lines. The results were then used to predict full scale performance and design methods were suggested.. Several alterative configurations were considered and recommendations for possible adoption made.

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TABLE OF CONTENTS

NOMENCLATURE

In this report, dimensions are given as ENG (SI). If no units are given then the quantity is nondimensional.

A = plan area of box, ft (m)
D_P = diameter outlet pipe (same as inlet), ft (m)
D_B = hydraulic diameter of box, ft (m)
D_C = diameter conflict pipe, ft (m)
f = D'arcy-Weisbach friction factor
g = acceleration of gravity, ft/s^2 (m/s^2)
h_l = head loss, ft (m)
H = elevation, ft (m)
H_B = elevation in box, measured from datum, ft (m)
H_1 = elevation in supply tank, ft (m)
H_2 = elevation in sump, ft (m)
K = loss factor
K_{JB}= junction box loss factor
K_e = supply entrance loss factor
K_{CB}= conflict box loss factor
Q = flow rate, ft^3/s (m^3/s)
Re = Reynolds Number
S_h = horizontal position for conflict, ft (m)
S_v = vertical position for conflict, ft (m)
V = velocity, ft/s (m/s)
WP = wetted perimeter of plan area of box, ft (m)

CONVERSION FACTORS

To convert	British	SI	multiply by
Acceleration	ft/s^2	m/s^2	3.048E-1
Area	ft^2	m^2	9.290E-2
Density	$slugs/ft^3$	kg/m^3	5.154E+2
Length	ft	m	3.048E-1
Pressure	lb/ft^2	N/m^2	4.788E+1
Velocity	ft/s	m/s	3.048E-1
Volume flowrate	ft^3/s	m^3/s	2.832E-2
Volume flowrate	gal/min	l/s	6.310E-2

Constants

Acceleration of gravity	32.19 ft/s^2	9.81m/s^2
Density of water	1.94 $slugs/ft^3$	1000 kg/m^3
Manning's constant	1.485	1.0

SUMMARY

Conflict junction boxes are employed at the intersection of utility lines and stormwater drains to avoid moving the utility. It is important to minimize both the flood risk associated with poor design and the cost of the installation. Accordingly, an initial study of the hydraulic performance of conflict manholes was completed in 1996. The work reported here is essentially a continuation and extension of this previous effort, which focused on conflict lines centered on the drainline. Here, the vertical position as well as the diameter of the conflict pipe was varied, and somewhat smaller box sizes were tested. A range of configuration ratios for square, rectangular and round boxes were examined.

Confirming the results of the previous study, it was found that the hydraulic losses for the box/conflict combination could be represented by a turbulent loss factor, the constant of proportionality between the loss and the kinetic energy of the flow in the drainline. Losses increased dramatically as the drainline was more obscured by the conflict, as would be expected. The results of this investigation were correlated with the position and size of the conflict and a design method has been developed. The losses associated with sumped conflict manholes were also investigated and the results show some promise for loss reduction, especially when circumstances permit no other solution.

INTRODUCTION

When stormwater drainlines intersect and a flow junction is required, a manhole junction box is installed. In a similar manner, conflict manholes are employed when utility conduits traverse a drainage line, except that isolation is maintained between the flows. As shown in Figure 1, the intersection occurs inside the box, and blocks the flow to some extent inducing additional hydraulic losses. Loss of flow capacity in the system results from these intersections or junctions.

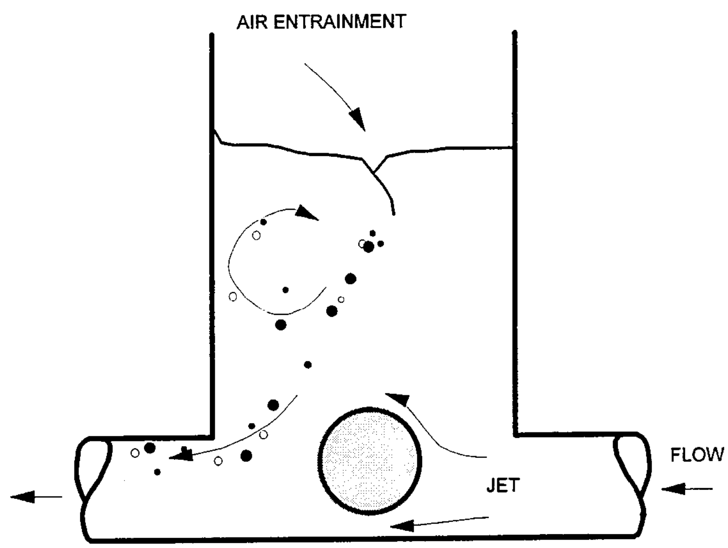

Figure 1: Typical conflict junction box installation. Note disruption of the inflow jet by the conflict pipe, and the mechanism of air entrainment by action at the water surface in the box (from [2]).

The Florida Department of Transportation has established some guidelines for the installation of conflict junction boxes (Index Number 201, Roadway and Traffic Design Standards [1]). Usually, only cast iron or steel water mains or cast iron sanitary sewers are allowed. Joints are not permitted inside a "Condition I" conflict manhole and for water mains only, a joint inside the conflict box is permitted if a sleeve covers the pipe (referred to as "Condition II"). This sleeve is to be formed from two half pipes, steel or cast iron, continuously welded water tight, and supported by cradles at the sides of the box. Practical issues include access for trash removal and physical size of conflicts and pipe. A 1.0 ft (0.31 m) minimum clearance between the bottom of the conflict pipe and the invert of the drainline is required, again to forestall blockage and to permit a better flow channel. Drawings indicate flat bottomed boxes only with no benching, but sumped (dropped) bottoms are also allowed under some conditions.

Motivated by the possibility of flooding due to the lack of design information, during the period 9/94 to 5/96 a series of experiments sponsored by the Florida Department of Transportation were conducted at the University of South Florida to examine the hydraulic performance and loss mechanisms associated with conflict junction boxes. This study [2] focused on conflicts positioned at the middle of the box and on the center of the drainline. Experimental results from this study indicated that losses encountered for this configuration could be correlated with the kinetic energy and reported as a turbulent loss factor. Losses can reach significant levels in some installations.

In practice, a wide range of conflict vertical positions is possible, and furthermore it is highly desirable to keep the conflict box as small as possible, for economic reasons. Accordingly the investigation reported here was initiated to provide design information for a wider range of box/conflict configurations. This investigation relies heavily on the discussion presented in the previous final report [2]. While losses in junction boxes has been extensively investigated [3-12], a search of the literature has failed to reveal any information concerning additional energy losses due to flow obstruction or modification resulting from the installation of a conflict junction box.

LOSS MECHANISM FOR CONFLICT JUNCTION BOXES

For turbulent flow in pipes under pressure, energy losses associated with fittings and hydraulic structures are frequently correlated directly with the velocity head:

$$h_l = K\frac{V^2}{2g} \tag{1}$$

These losses are often termed "minor losses" and for design purposes, the loss factor, K, is assumed to be approximately constant with flow velocity, over the range of flow Reynolds numbers typically encountered. The fundamental assumption of the work reported here (as well as in the previous investigation [2]) is that both plain and conflict junction boxes flowing under substantial head (with equal inflow and outflow velocities) can also be treated in this manner.

DIMENSIONAL RELATIONSHIPS

A definition diagram of a typical conflict junction box is presented in Figure 2. Except as noted, most experiments performed here were restricted to cases where both the inlet pipe and the outlet pipe are equal in diameter and in line, with the invert of both pipes flush with the bottom of the junction box.

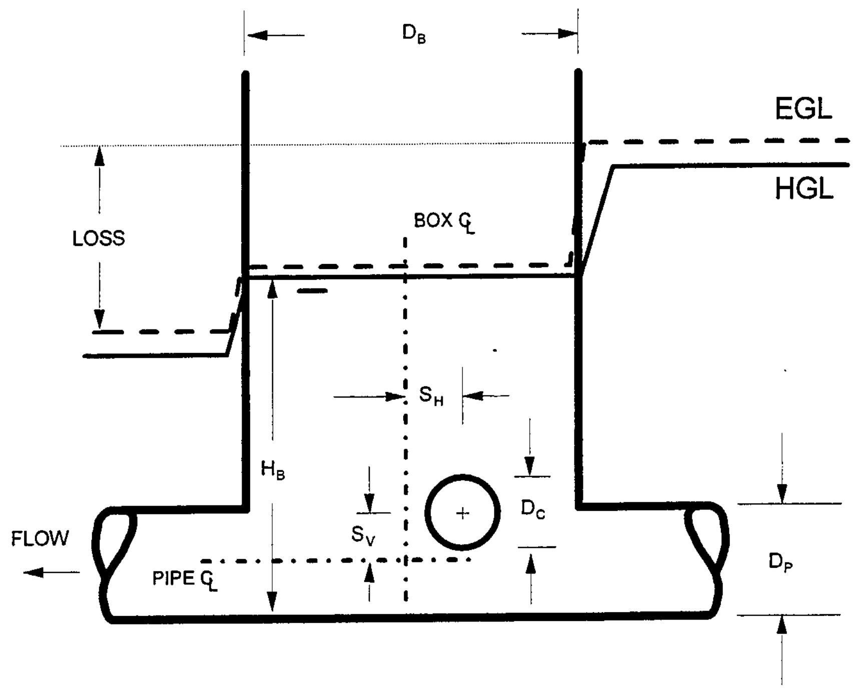

Figure 2: Configuration of conflict junction box, indicating nomenclature and definitions (from [2]).

As in Reference 2, geometrical parameters can be formed by normalizing the various dimensions to the diameter of the stormwater pipe, D_P. Junction boxes with both round and square/rectangular plans are used in practice. In the previous study, the diameter or side dimension of round and square boxes was used to characterize the box size, and to facilitate comparisons the hydraulic diameter of the plan area, D_B=4A/WP (where WP is the wetted perimeter), was used as a measurement for rectangular boxes. Here, an alternative choice of the transverse dimension of rectangular boxes (parallel to the flow) has been adopted. The reason for this change is that the selection of rectangular configurations is primarily to accommodate larger drainpipes while minimizing the size of the box. Furthermore, as will be seen later in this report, the transverse dimension appears to be the most important influence on flow losses. This choice is somewhat arbitrary however, and might be subject to future revision if circumstances warrant.

Geometrical parameters are thus defined as:

D_C/D_P, the ratio of conflict pipe to stormwater pipe diameter
D_B/D_P, the ratio of box size to stormwater pipe diameter
H_B/D_P, the submergence ratio of the outlet, measured from invert
S_v/D_P, vertical spacing ratio of conflict pipe, measured from centerline of drain
S_h/D_P, horizontal spacing ratio of conflict pipe, measured from centerline of drain

A fundamental assumption in this investigation is that scaling is not a factor in determining the value of the loss coefficient, just the geometrical ratios defined above. In addition to the various geometrical parameters, the flow can be described by forming the Reynolds Number and the Froude Number (the effect of surface tension, as described by the Weber Number is neglected in the study). Fully developed turblent flow around the conflict can be expected, as well as in the pipe. Under these conditions, the loss coefficient is not expected to be a strong function of the Reynolds Number, and assuming submerged flow, the Froude number is not expected to be an important parameter.

Tables 1 and 2 present dimensions of conflict box configurations used in practice and in the present study, respectively.

Table 1: Summary of some typical dimensional combinations of D_P, D_C and D_B (provided by the Florida Department of Transportation).

DRAIN(FT)	RECTANGULAR SIZE(FT)	DB/DP	ROUND SIZE	DB/DP
1.25	3.5 SQ	2.8	3.5, 4.0	2.8, 3.2
1.50	3.5 SQ	2.3	3.5, 4.0	2.3, 2.7
2.00	3.5 SQ	1.75	3.5, 4.0	1.75, 2.0
2.50	4.0 SQ OR 3.5x4	1.6,	5	2.0
3.00	4.0 SQ OR 3.5x4	1.3, 1.2	6	2.0
3.50	3.5 OR 4x5	1.2, 1.3	6	1.7
4.00	3.5 OR 4x6	1.1, 1.2	8	2.0
4.50	3.5 OR 4x6	1.0, 1.1	10	2.2
5.00	3.5 OR 4x7	0.9, 1.0	12	2.0
5.50	3.5 OR 4x8	0.9, 1.0	12	2.2
6.00	3.5 OR 4x8	0.8, 0.9	12	1.7

In practice, storm drains vary from 1.25 ft to 6 ft in diameter and a likely upper limit for storm sewer velocities of 10 fps can be anticipated. Conflict pipes may vary widely in size, but a practical range of 0.3 ft to 2 ft is assumed. These dimensions fix the approximate geometrical ratios encountered in practical situations. Setting the narrow dimension along the flow path means that the rectangular box to pipe ratio can be less than one, but $D_B/D_P=1$ is a lower limit for square boxes. Here clearance for the conflict and access for cleaning is the principal limitation. The selection of round boxes results in larger box ratios; for example, a 6 ft pipe and a 12 ft diameter box would give D_B/D_P=2.

Also restricting the range of practical configurations is the arbitrary requirement of a one foot minimum clearance for all conflict pipes. It should be noted that this dimension does not scale in the same manner as a geometrical ratio, and compliance must be independently verified.

The various model conflict boxes (Table 2) were constructed to dimensions to approximately bracket the geometrical ratios shown in Table 1. In this investigation, for convenience in all tests the inlet and outlet pipe internal diameters were held at a diameter of 0.5 ft.

Table 2: Junction box model and conflict pipe sizes used in this investigation (D_B and D_C are reported as inches)

SHAPE	DB	DB/DP
SQUARE	7.25	1.2
SQUARE	9.00	1.5
SQUARE	10.50	1.8
SQUARE	16.75	2.8
RECTANGULAR	4.00	0.7
RECTANGULAR	6.00	1.0
ROUND	8.00	1.3
ROUND	9.88	1.6
ROUND	15.88	2.6

DC	DC/DP
1.31	0.22
2.38	0.40
3.50	0.58
4.50	0.75
6.63	1.10
8.63	1.44

Thus the following parameter ranges were investigated; D_B/D_P: 0.68 to 2.8, D_C/D_P: 0.22 to 1.44, D_C/D_B: 0.14 to 0.86, and S_V/D_P: -0.17 to 1.17. While these values generally straddle the values found in practice, not every combination within these ranges were investigated (cf Appendix A).

GOALS OF THE PRESENT INVESTIGATION

In the present study (as in the previous investigation), square, circular and rectangular conflict junction boxes were tested for hydraulic performance. This study represents an extension of the previous work however, in that here the size of the boxes relative to the inlet pipe was smaller, the conflict pipe sizes were in some cases relatively larger and the influence of vertical position was extensively investigated. Furthermore, an examination of the sumped manhole configuration was also made.

It is highly desirable to use smaller boxes to reduce installation costs. Such choices lead to larger conflict to box ratios and based on the previous investigation, it is expected that losses would increase. Additional testing in this regime is necessary to understand the consequences of moving in the direction of smaller boxes.

The ultimate goal of the present investigation is to provide more design information concerning losses for conflict junction structures under conditions closely related to practical situations, especially the influence of vertical conflict position. Only a limited investigation of this area was made during the previous study and the results were not conclusive. Here the focus is on straight-through junction boxes (no top or lateral flow) having inlet and outlet pipes of the same diameter, with the invert of the pipes flush with the bottom of the box. For most of this study, the only flow mode considered was the case of pressurized flow in the conduit (full flow). This restriction means that the water elevation in the junction box will be substantial so that both the conflict line and the stormwater conduit lines are fully submerged.

EXPERIMENTAL FACILITY AND OBSERVATIONAL METHODS

Model junction boxes were constructed from plywood or PVC and polyester resin with PVC inlet and outlet pipes. The inlet and outlet pipes were flush with the bottom of the box for all models except as noted. In the present investigation the relative roughness of the surface was not investigated as a parameter. The prototype surface of the conflict pipe was assumed to be relatively smooth metal or plastic and the box assumed to be finished concrete. During the course of this investigation, square, round and rectangular box configurations were examined, as before. A schedule of configurations examined in the main body of tests is shown in Table 2. All tests were conducted with a constant inlet/outlet pipe diameter and the conflict pipe normal to the flow.

The experimental facility used in this and previous investigations consisted of a large fiberglass tank, 12x6x6 ft acting as a sump. Two centrifugal pumps completed the loop between a vertical riser and the sump tank. These pumps can be operated independently or in parallel. The flow rate in each pump line was separately measured by an electronic flow sensor. A long line (with additional flow monitoring) connected the riser to the junction box. The return line included a valve to control the elevation in the box. A sufficient waiting period to stabilize the system between changes was maintained.

Most previous investigators of the performance of junction boxes have made extensive measurements of the slope of the hydraulic grade line along each branch and projected these results back to the box. This method was necessary due to multiple branching at the junction. Here a much simpler method has been used, requiring the measurement of the elevation of the hydraulic gradeline at two points, at considerable distance from the junction box. In the previous investigation, upstream and downstream reservoirs were used. As shown in Figure 3, in the present investigation a point 7 pipe diameters

upstream and a point 16 diameters downstream were selected to avoid the depression in the hydraulic grade line immediately downstream of the box.
The static pressure upstream and downstream of the junction box was observed by means of standpipes with a minimum resolution of 0.005 ft. Water elevation in the box was measured directly. Normally, the water elevation in the box was sufficient to submerge the drainline (this issue will be discussed further in the material that follows).

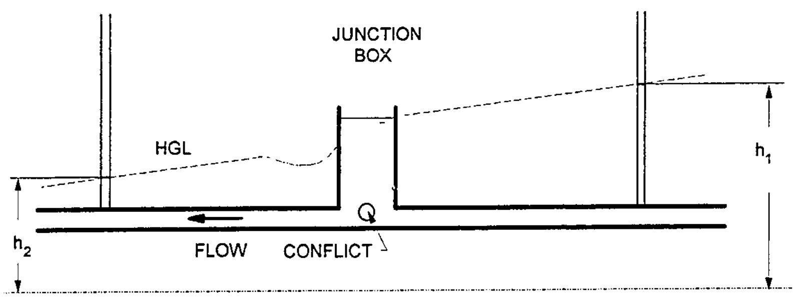

Figure 3: Hydraulic grade line developed for the experimental configuration.

The measurement of the losses incurred at the junction box were made by determining the loss for the junction box and associated piping, then subtracting the losses due to the pipeline. Losses for a range of flow conditions were measured, then the loss factor was determined by linear regression for the loss versus kinetic energy relationship according to Equation 1. The underlying loss was measured first by inserting a short length of pipe in place of the conflict box then observing the difference in the hydraulic grade line at the two measurement stations for several flow rates. The loss factor was determined in the same manner as for the conflict boxes to be 0.28 in one set of experiments and 0.39 in another set.

For comparison, losses in the pipeline can estimated from the D'arcy-Weisbach relation

$$h_l = \frac{fL}{D_P}\frac{V^2}{2g} \qquad (2)$$

If the friction factor f=.015, a pipe loss factor of 0.34 might be expected. The difference between the two experimental measurements is probably the result of random error plus a systematic difference, possibly due to slight misalignment at the small section of pipe inserted at the box position. One-half of this difference may provide a reasonable estimate of experimental error for all loss coefficients.

RESULTS FOR SIMPLE JUNCTION BOXES

As discussed previously, it is usually argued that for pressure flow, K is independent of velocity so long as the flow is fully turbulent and does not approach free surface flow. For ordinary junction boxes, this means that the overt of inlet and outlet pipes must be submerged by about one pipe diameter (H_B/D_P=2). The most simplistic treatment of the total box loss would be to assume that the loss can be treated as an exit loss as the flow enters the junction, coupled with an entrance loss as the flow leaves. Maximum values for these two loss factors are 1.0 and 0.5, respectively, so that the total loss might approach 1.5. Since this figure is much higher than observations, it has been suggested by Pedersen and Mark [10] that the entering jet is not fully dissipated within the box but rather is partially captured by the exiting pipe, thus preserving some kinetic energy through the box. This theory has been relatively successful in predicting the actual losses encountered in straight through junctions. The authors have presented a simple empirical fit for the case of flush entrance and exit, rating the whole box as a single loss:

$$K_{JB} = .12\frac{D_B}{D_P} \qquad (3)$$

This correlation is based on experiments restricted to D_B/D_P ratios of 1 to 4.5. An alternative correlation for this configuration has been suggested in Reference 12.

$$K_{JB} = \frac{0.9D_B/D_P}{6.0+D_B/D_P} \qquad (3)$$

This expression has an asymptotic value of 0.9, but the range of the data is relatively small for both correlations. For a very large box, the entering jet may be completely dissipated. In this case, the loss factor should approach the limiting value of 1.5. Both of these correlations, a collection of previous data and the results of the present investigation, are presented in Figure 4. The composite results, as well as the model, indicate that losses induced by the addition of a manhole increase with the size of the box. The results of the present investigation indicate a somewhat lower loss factor than the empirical correlation of [10] (which did not include all of the data shown on the graph. This difference does not appear to be scatter and, barring systematic error, it appears that the previous correlations may be slightly high.

As discussed previously, there is good reason to believe that as the box size becomes very large the loss factor should approach the value of 1.5. In fact, the straight line correlation proposed in [9] and shown in Figure 4 is for convenience only rather than having a rigorous basis, and should have this asymptote for large box size. Also included is a correlation proposed in [12]. When the results of all investigations are taken in to account, it does appear that the limiting behavior may occur at a higher value of D_B/D_P than indicated by this latter correlation.

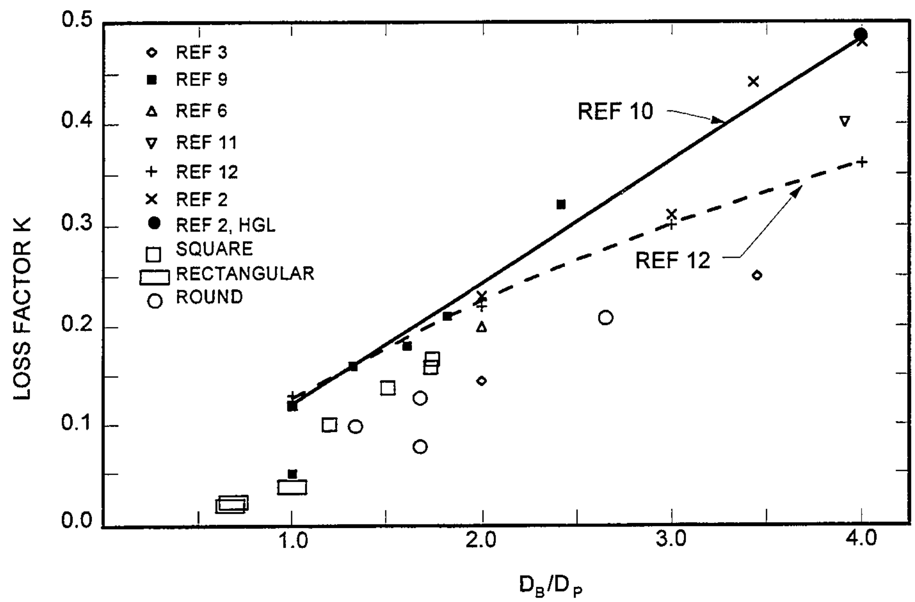

Figure 4: Empirical correlations for the loss coefficient associated with simple two port junction box (no conflict) with experimental measurements from several sources, including this investigation.

RESULTS FOR CONFLICT JUNCTION BOXES

Reasoning similar to that presented above for simple two-port junction boxes may be applied to the total losses induced by a junction box when intersected by a transverse conflict pipe. Again, the box plus the conflict is rated as a single, overall loss, defined as the drop in the hydraulic gradeline (HGL) across the box. Here however, the transverse pipe promotes the breakup of the transverse jet and enhances the dissipation of kinetic energy, so that losses may be substantially increased. It is possible that the jet may remain partially intact but deflected at an angle to the entrance of the exit pipe.

Although the exit loss incurred at the box entrance is always limited to $K_{exit}=1$ under the assumptions of the model, there is no limit to the loss at the redevelopment of flow exiting the box. A free and clear flow path is typically rated at K_{ent}=0.5 however a large conflict pipe in close proximity to the entrance could represent a substantial blockage much like a valve structure, so that the overall K factor could rise to large values (much greater than K~1.5).

Reference 2 documented an experimental investigation of the hydraulic performance of typical two pipe junction manhole configurations with conflicts. Previous investigators have found that the loss increases with box size, for straight through flow in an empty junction box. As would be expected, the addition of a conflict pipe causes a further increase in the loss, depending directly on the size of the pipe. Furthermore, the loss increases when the conflict pipe is large in relation to box size. A major finding of the previous investigation was as follows:

> "As the size of the conflict pipe relative to the inlet pipe diameter increases, so do the total losses associated with the conflict junction box. The effect of a second factor, the size of the conflict pipe relative to the size of the box are interrelated with the effect of box size. ..... when no conflict is present, the loss factor increases with the size of the box, but this trend is not apparent when conflicts are present. Instead, the combination of small boxes and large conflicts causes an elevated loss factor. The probable cause of this effect is partial blockage of the box by the conflict pipe. " [2]

Actual values of the loss factor with conflict were always greater than the simple two port junction boxes and under some conditions tested was near the value 1.5, indicating near complete dissipation of the jet. Only a few conditions were identified with loss factors greater than 1.5.

In the work reported previously, experiments were focused primarily on conflicts centered in the box. In the present investigation, a much more extensive examination of vertical positioning was made (but except as noted a centered horizontal position was maintained). Consequently the data were taken according to a different schedule. For a particular box geometry, an appropriate range of conflicts were tested, each at several different vertical positions spanning a range of possible values (different for each box). This approach is also reflected in the presentation of results, where the vertical spacing ratio has become the primary parameter of interest, with the box to pipe ratio as a secondary variable.

The relation between the loss coefficient for junction boxes containing conflicts at a particular vertical position and the relative conflict size is shown in Figures 5-7. Here, each data point represents the slope of the loss vs kinetic energy plot and so utilizes a number of actual data points. The slope of the total loss plot was obtained by a least square regression, then as discussed previously, the underlying loss due to the piping system was subtracted to give the loss coefficient for the box with conflict. No attempt was made to separate the loss of the box itself from the introduction of the conflict.

Square boxes

Figure 5a-d show the results for the loss factor as a function of vertical position for several confict sizes. In all cases the trend shows an increasing loss as the conflict size is increased or the conflict is lowered toward the centerline. The limiting case is the empty box which has a relatively small loss.

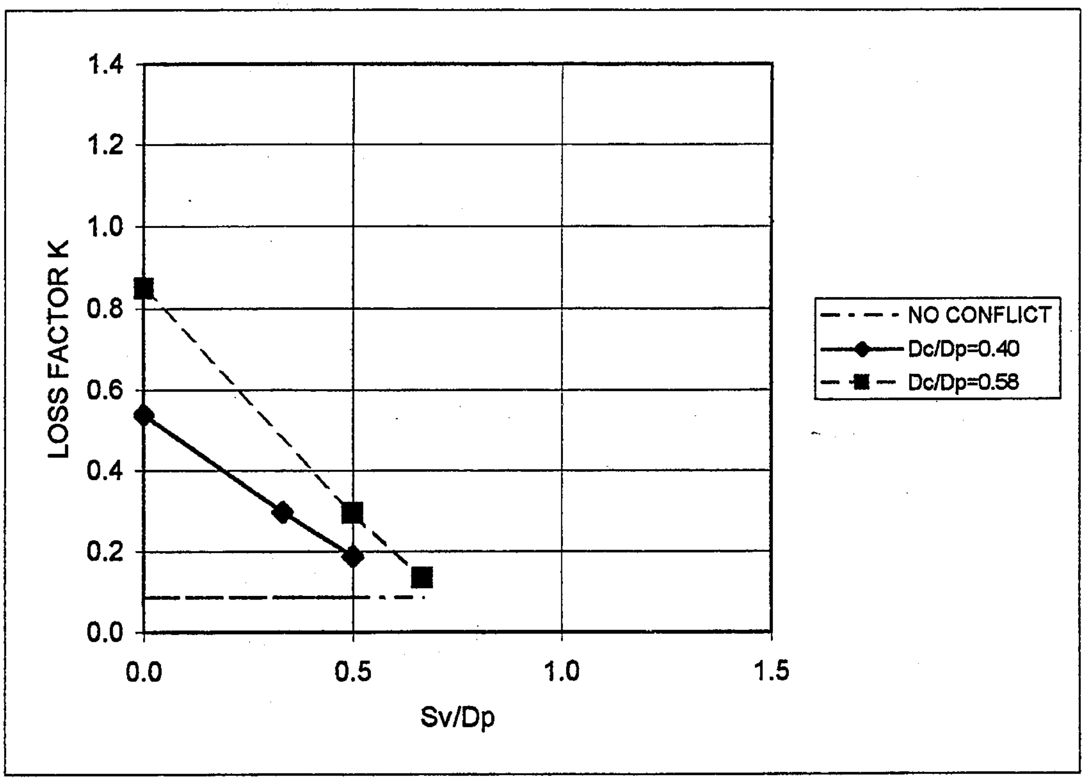

Figure 5a: Loss coefficient as a function of vertical spacing ratio for various square conflict junction box configurations. Box size D_B/D_P= 1.2. Loss coefficient for a simple two port junction box of the same size indicated for comparison.

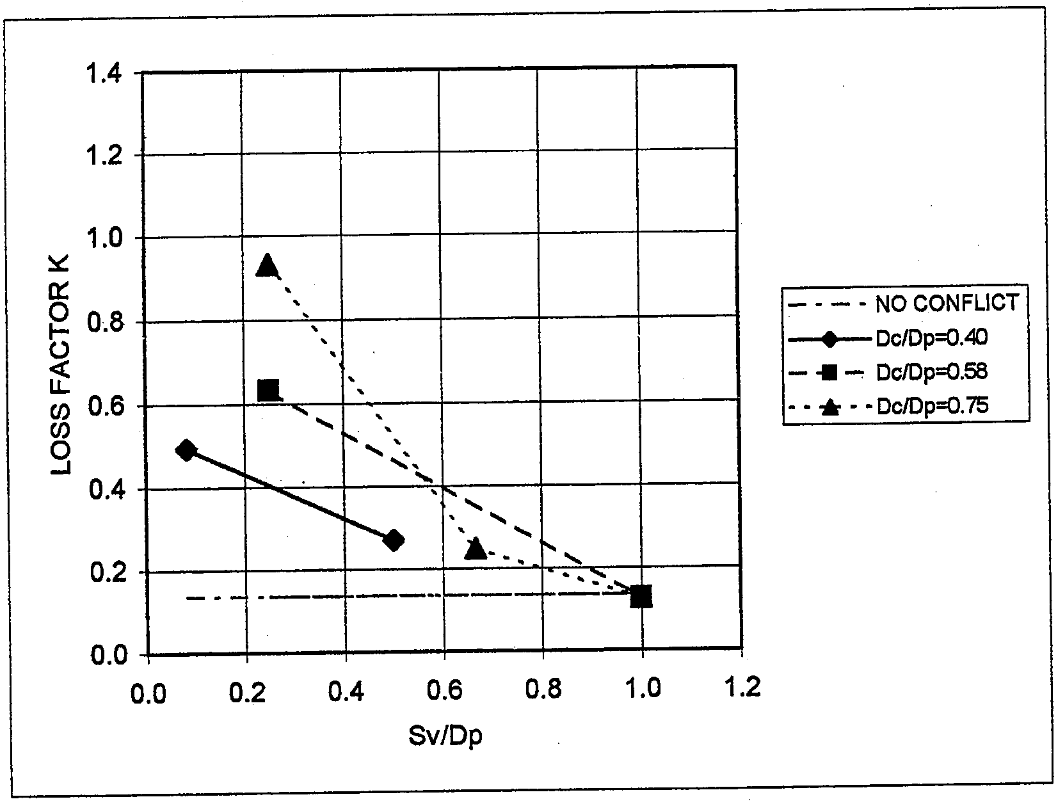

Figure 5b: Loss coefficient as a function of vertical spacing ratio for various square conflict junction box configurations. Box size D_B/D_P= 1.5. Loss coefficient for a simple two port junction box of the same size indicated for comparison.

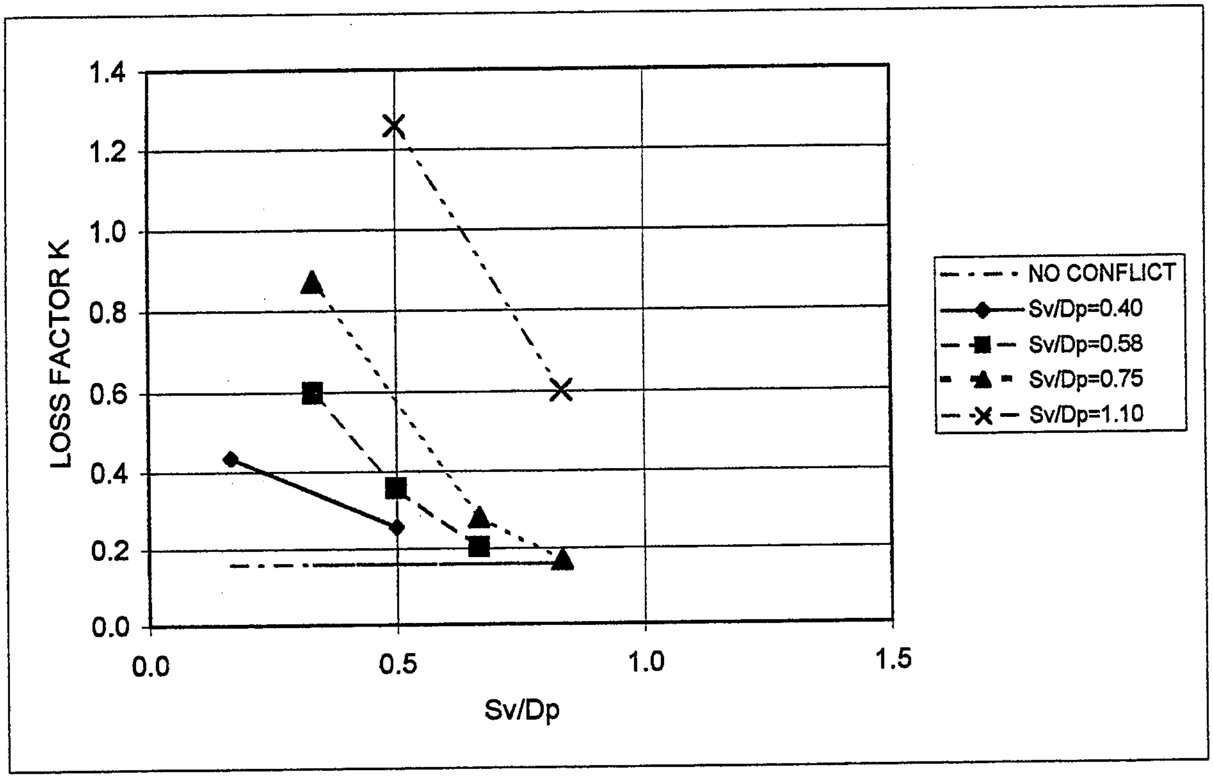

Figure 5c: Loss coefficient as a function of vertical spacing ratio for various square conflict junction box configurations. Box size D_B/D_P= 1.75. Loss coefficient for a simple two port junction box of the same size indicated for comparison.

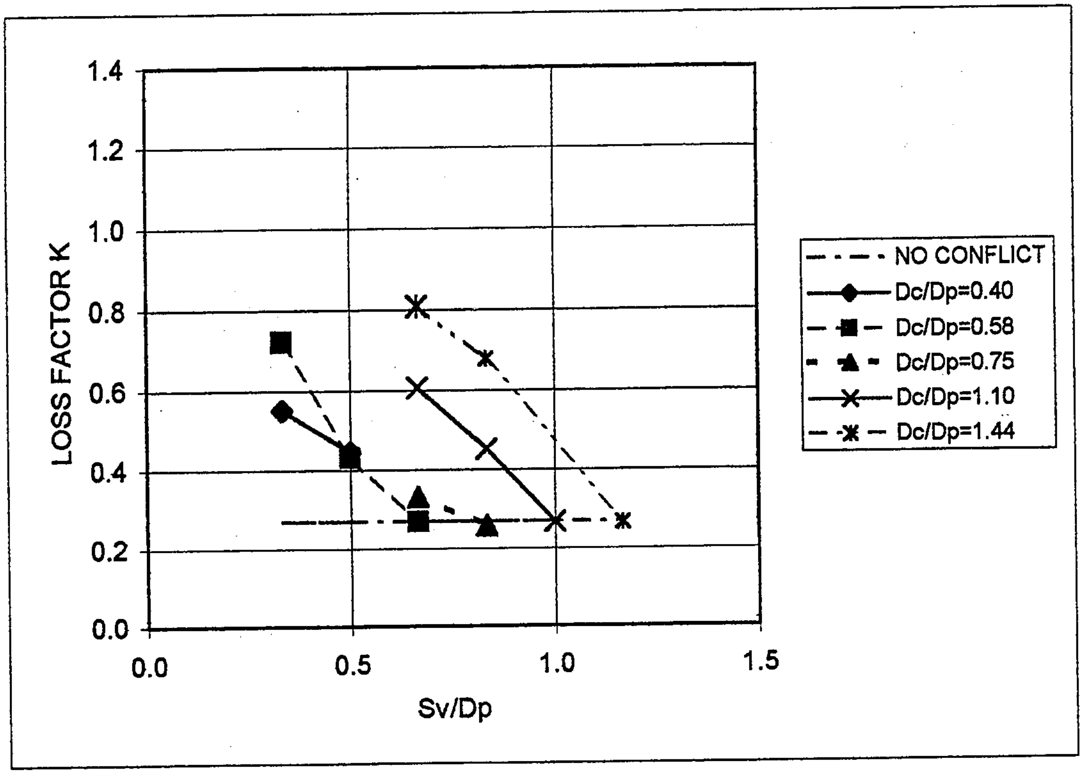

Figure 5d: Loss coefficient as a function of vertical spacing ratio for various square conflict junction box configurations. Box size D_B/D_P=2.80. Loss coefficient for a simple two port junction box of the same size indicated for comparison.

Rectangular boxes

The results for rectangular boxes have been presented in a similar manner to those for square boxes. Results for the smaller box size was duplicated in an independent test for reproducibility comparisons. The range of conflict diameters was extensive, and the results gave loss factors in the neighborhood of 1.5 in some cases, indicating a degree of box blockage.

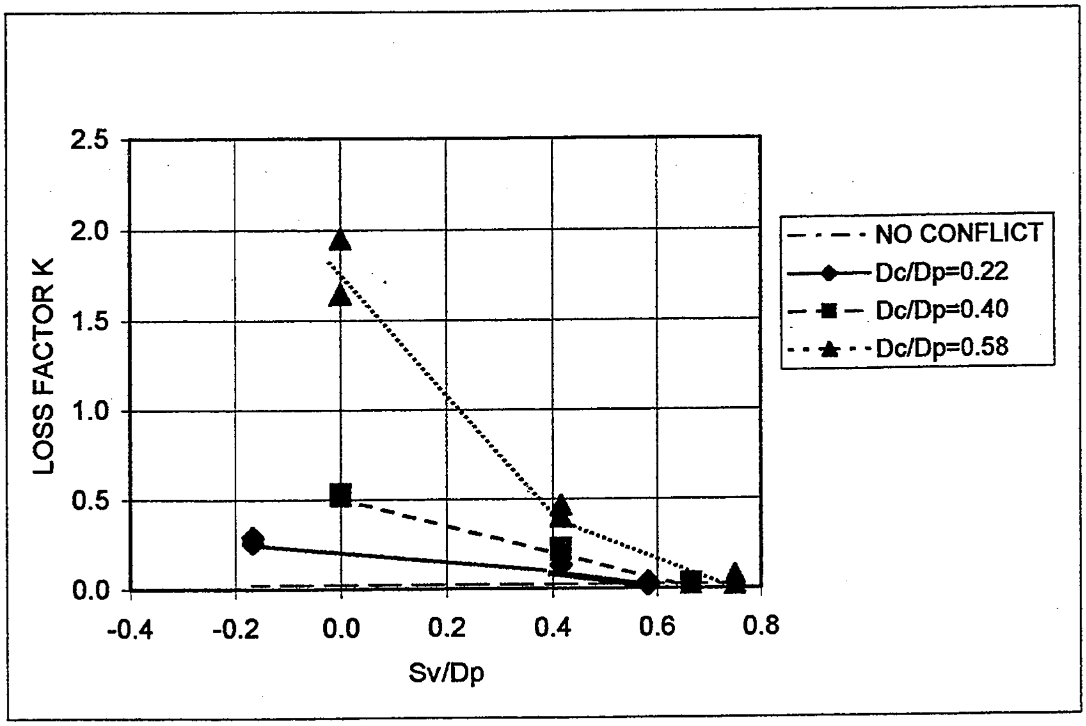

Figure 6a: Loss coefficient as a function of vertical spacing ratio for various rectangular conflict junction box configurations. Box size D_B/D_P= 0.68. Loss coefficient for a simple two port junction box of the same size indicated for comparison (twice the number of points were acquired as a reproducibility check).

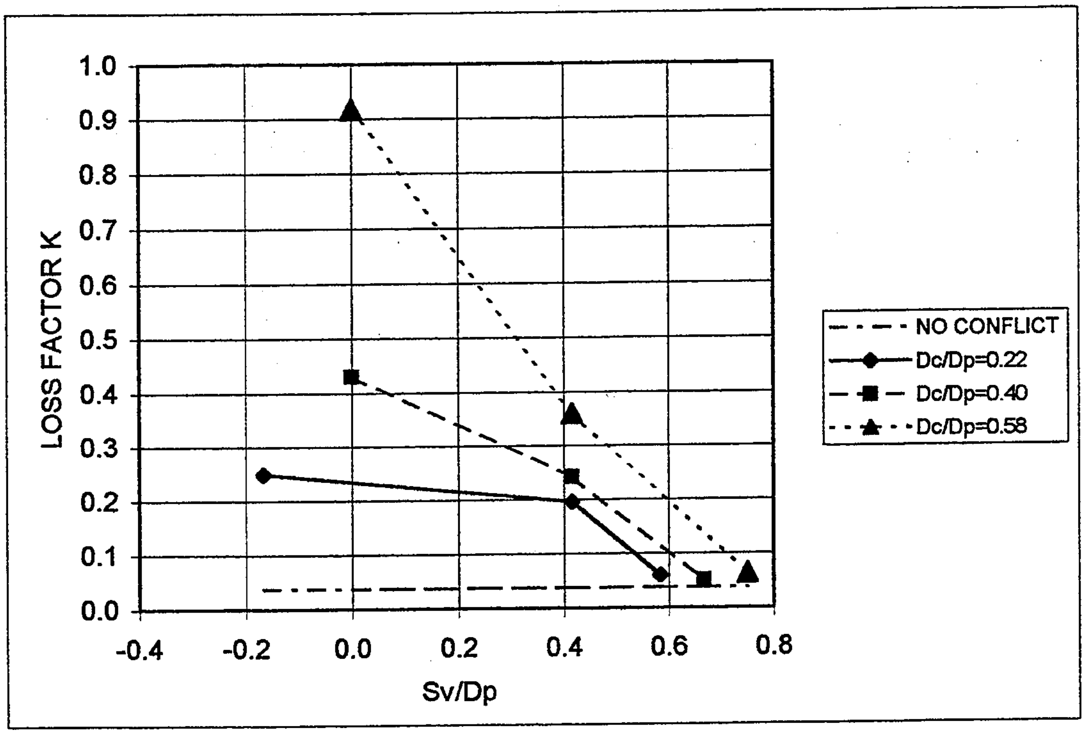

Figure 6b: Loss coefficient as a function of vertical spacing ratio for various rectangular conflict junction box configurations. Box size D_B/D_P= 1.0. Loss coefficient for a simple two port junction box of the same size indicated for comparison.

Round boxes

Results for round boxes were presented in a similar fashion as those for the two previous configurations.

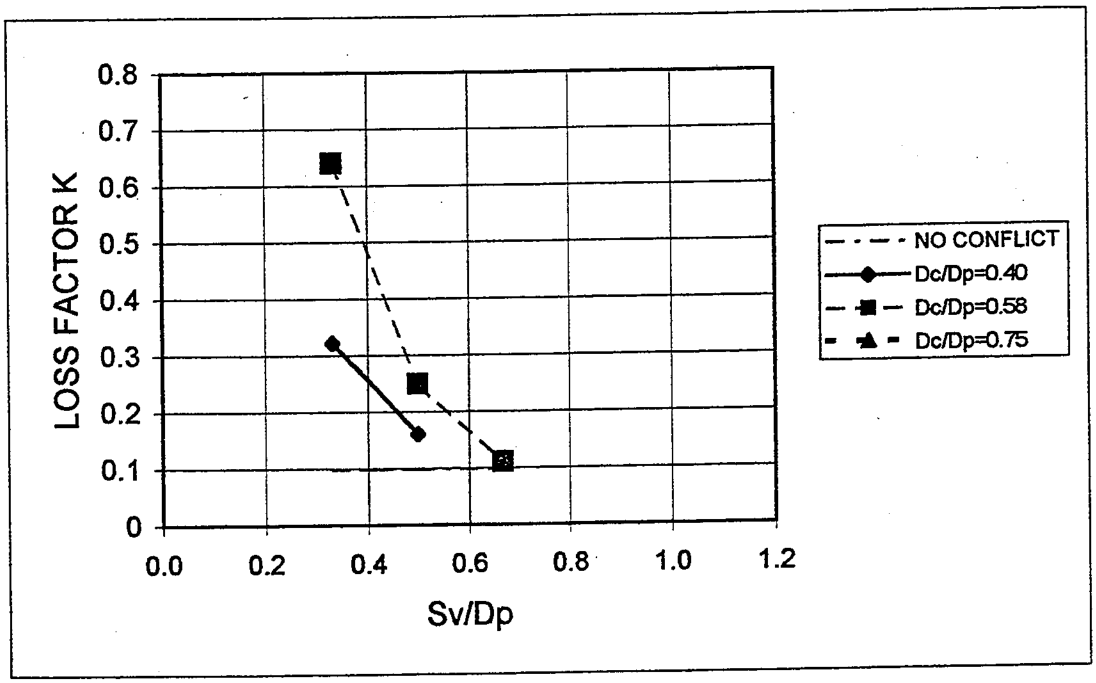

Figure 7a: Loss coefficient as a function of vertical spacing ratio for various round conflict junction box configurations (square end pipes). Box size D_B/D_P=1.33. Loss coefficient for a simple two port junction box of the same size indicated for comparison.

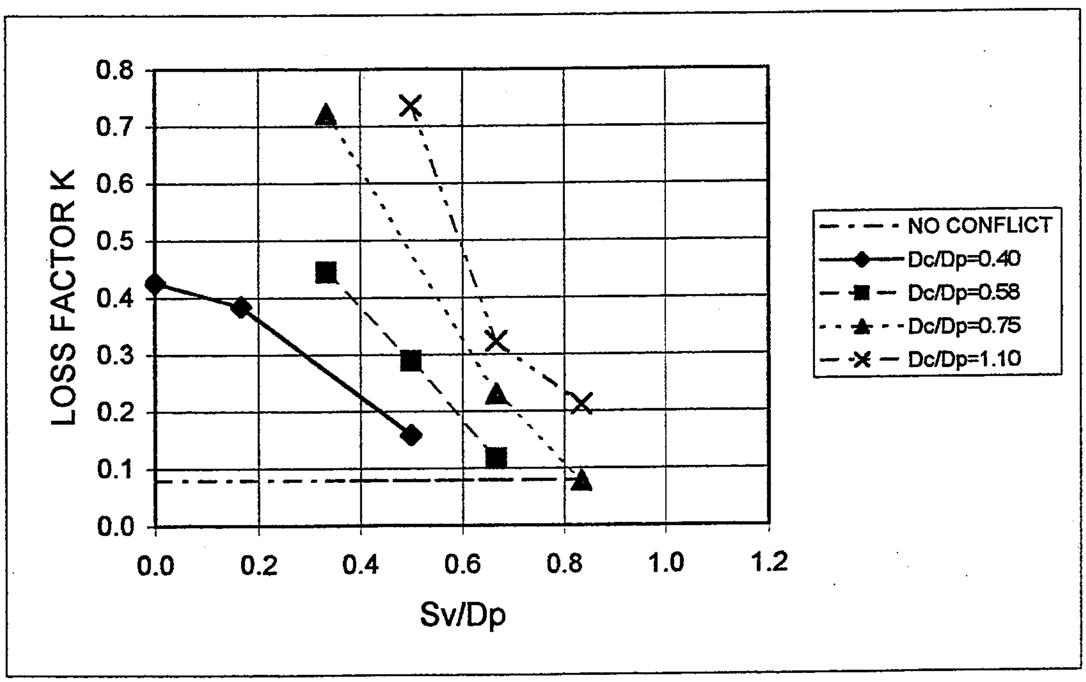

Figure 7b: Loss coefficient as a function of vertical spacing ratio for various round conflict junction box configurations (square end pipes). Box size D_B/D_P=1.67. Loss coefficient for a simple two port junction box of the same size indicated for comparison.

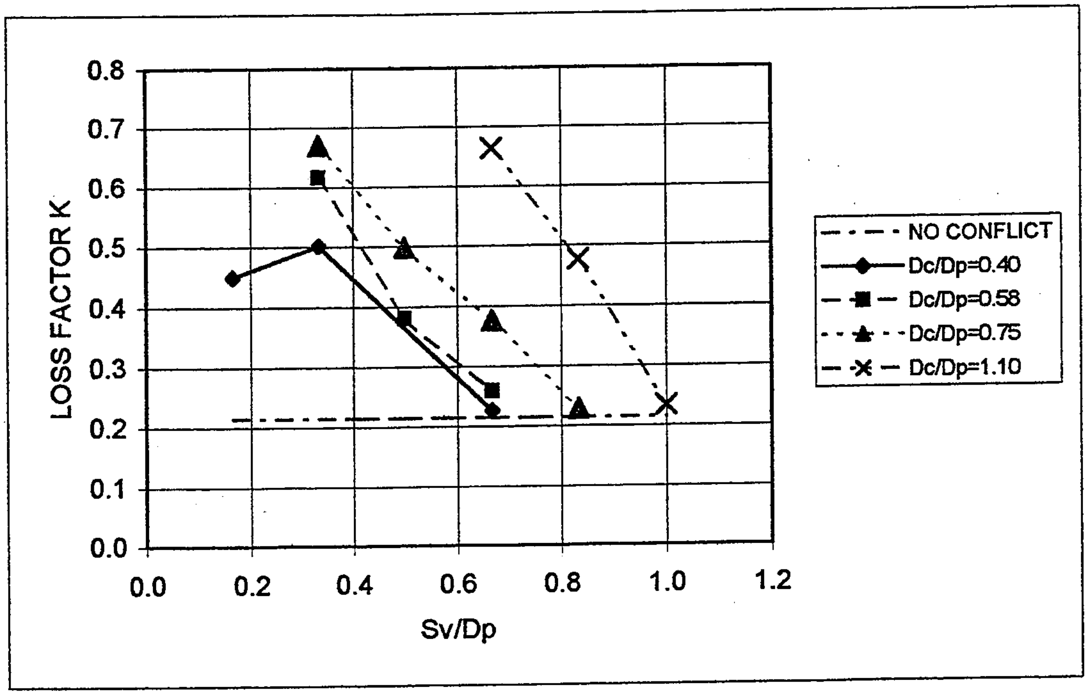

Figure 7c: Loss coefficient as a function of vertical spacing ratio for various round conflict junction box configurations (square end pipes). Box size D_B/D_P= 2.67. Loss coefficient for a simple two port junction box of the same size indicated for comparison.

One question not completely addressed in the FDOT Index concerns the intersection of the drainline and circular conflict boxes. For square and rectangular boxes, assuming that the drainline meets the box at right angles and that the end of the pipe was square, the resulting exit and entrance configurations are simple. For circular boxes, however, the intersection between the drainline and the box can be more complicated. If the end of the pipe is simply left square then the pipe end protrudes into the box, limiting the horizontal clear area. On the other hand, if the pipe end is faired to the box wall (or merely broken off as is sometimes done in the field), a different geometry is obtained. A limited series of tests were conducted to examine the influence of the differences in pipe end shapes on the loss factor for circular boxes.

In all the experiments reported thus far the pipe end was square. Once the tests for the circular box (D_B/D_P=1.67) were completed, the pipe ends were reshaped to conform to the wall and this series was repeated for the same conflict conditions For this box, an identical set of tests was repeated with the pipe reshaped to conform with the box wall. The results are shown in Figure 8, presented as a 1:1 correlation. With the exception of two points at high loss, good correlation was obtained. No explanation for the two outliers (which come from different data sets) is apparent, other than the fact that these are the conditions of highest loss factor.

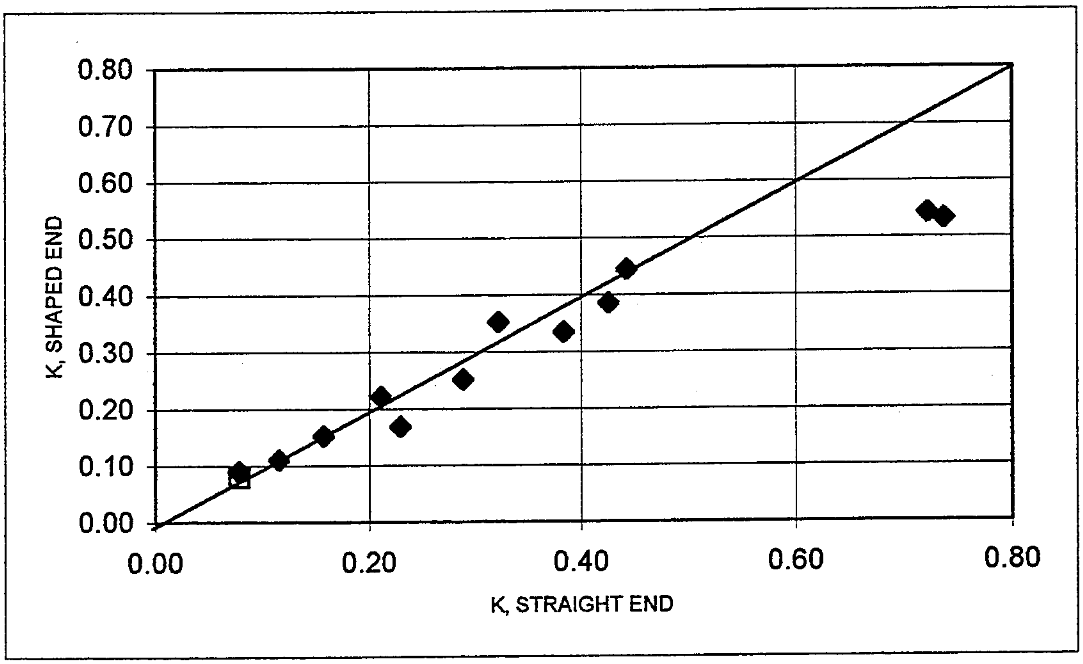

Figure 8: The effect of pipe end condition for circular box, D_B/D_P=1.67. Data for various size conflicts and vertical positions combined. Open data symbol represents the empty box condition.

RANGE OF DATA APPLICABILITY

As stated previously, the loss factor for a particular configuration should be approximately constant for a wide range of conditions (well developed turbulence, pressure flow). Submergence of the box inlet and outlet (to about one pipe diameter above the invert) is assumed but not always guaranteed. Under conditions of very high flow rates or box blockage by the conflict, it has been observed that the flow at the entrance can become starved. In these circumstances, it was possible that the hydraulic grade line at the entrance to the box exit pipe was lower than the overt of the pipe, leading to air aspiration into the exit. Although clearly undesirable, this case could also occur in practice. It is emphasized that the elevation of the hydraulic gradeline is controlled by the development of loss for the entire system and does not scale with the model.

In the previous investigation [2], it was stated that for low velocities the jet is nearly fully dissipated and K=1.5 for the box. This is true only at extremely low velocities, when the kinetic energy is virtually negligible. The results of this investigation indicate that the turbulent loss factor can be used over all reasonable velocities encountered in practice.

CORRELATIONS FOR DESIGN

Figure 9 is a composite of all data gathered for square, rectangular and round data (omitting the data for empty boxes). Grouping by D_C/D_P parameter is apparent but as presented, the data are not further identified by either box size parameter D_B/D_P, or the ratio of conflict to box, D_C/D_B. With modest spread (and some exceptions), the data for a particular conflict to box size ratio overlap for the different box geometries. This observation tends to support the use of the rectangular box dimension in the flow direction as the appropriate measure of size.

Thus, box size (as well as shape) is not a parameter in this figure and attempts to find meaningful correlations for the D_C/D_B (or D_B/D_P) ratio were not successful. This result does not imply that the box configuration is not important, merely that it is not a strong influence over the range tested (in fact, over a larger range tested in [2], some dependence was identified). The previous investigation showed that it was difficult to relate the losses in a simple fashion to the various geometrical ratios when the conflict was centered. Here, the addition of the vertical position as a variable further complicates interpretation.

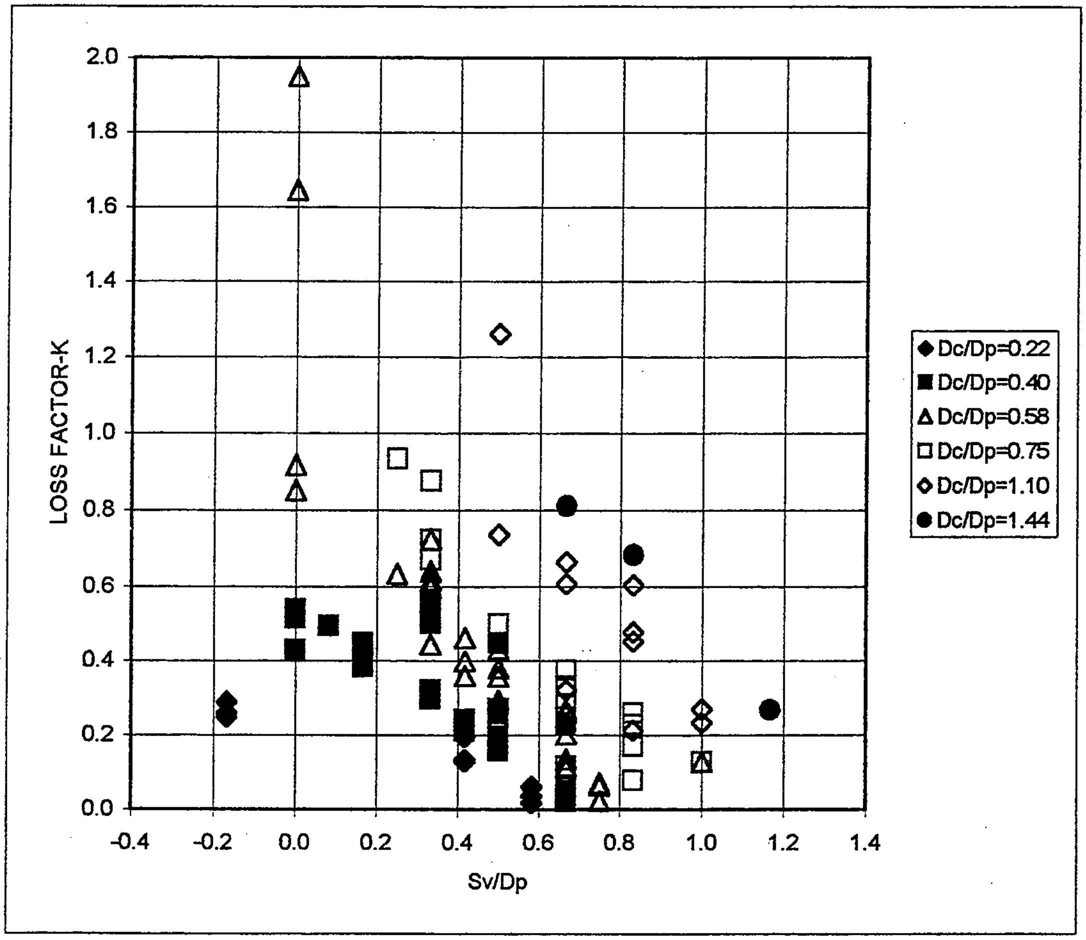

Figure 9: Data collected from tests performed (Figures 5, 6 and 7), organized as loss factor vs S_V/D_P ratio, grouped by D_C/D_P ratio, without regard to box configuration.

It is highly desirable to develop the data obtained during this investigation into design information. Accordingly, the following steps are proposed, based on a critical examination of the trends presented in Figure 9.

1. Relatively few data points represent K>1.0, and they are most often associated with a large conflict shadowing a large part of the jet in a small box, leading to box blockage. Design choices should be made to avoid these conditions if possible and it is suggested that these points be eliminated from further consideration.

2. Several points for D_C/D_P= 0.40 lie well above the general trend of the data for this set. Inspection shows that these points and several others as well are associated with D_C/D_B <0.14, corresponding to a small conflict in a large box. It is suggested that designs falling into this range be avoided as uneconomical. Eliminating these points means that design selections in this range should be avoided without special examination of the data.

3. Two points for D_C/D_P= 1.10 lie well below the trend for this group. It is suggested that these points be ignored, although no reason could be found for believing that these were errors. Ignoring these points will result in more conservative designs.

To assist in the design process (as explained below), these three recommendations have been implemented and trend lines have been computed for the remaining data as shown in Figure 10. These changes are also indicated in the data summary presented in Appendix A. To assist the designer, an alternative version of Figure 10 may be found in Appendix B.

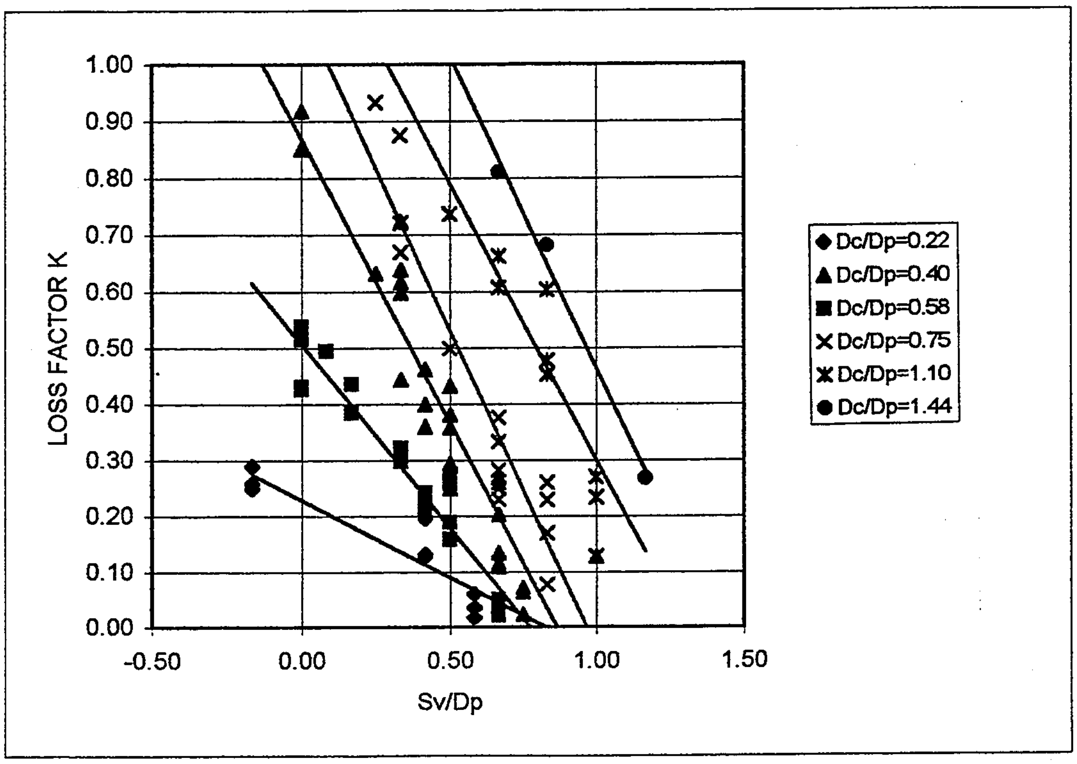

Figure 10: Loss correlations for design estimates. Empirical fits of data from Figure 9, excluding some points as discussed in text (cf Appendix A and B).

PROPOSED DESIGN METHOD

In formulating an approach to the problems faced in a typical design, it seems reasonable to assume that the practitioner would have a beginning estimate of the size of the storm drain line, the vertical elevations of that line and the conflict line and finally, a dimension for the conflict line. Thus two of the appropriate geometrical ratios defined previously can be computed directly (S_V/D_P, D_C/D_P). From these two parameters alone it is possible to estimate the losses for the box, as discussed earlier. Depth of water in the box can then be determined by constructing the hydraulic gradeline.

The principal task of the practitioner is then to select a configuration and size for the conflict box. This choice must reflect the influence of the resulting loss on the performance of the system, economic constraints, and physical constraints (ie. clearance and accessibility requirements). Clearance between the bottom of the conflict pipe and the bottom of the box (same as the drainline invert) must be checked for compliance with the one foot rule. This step is independent of other requirements. If the overall hydraulic performance of the system is not deemed acceptable, then box configuration must be changed, or the system redesigned (as for example, a larger drainline or a tandem installation).

To begin the design process, enter Figure 10 with the value for S_V/D_P, move up to the appropriate value of D_C/D_P (estimate between values as necessary) to obtain a trial value for K. The maximum loss estimate expected from the box can be obtained from Equation 1, using the maximum discharge expected and the drainline diameter to calculate the drainline velocity. Using this loss as a trial value, overall system performance can be estimated. If the predicted loss can be tolerated (for the elevational differences encountered), then any box size within the limits of the investigation can be chosen. Obviously, a smaller box will usually be a more economic choice (consistent with accessibility requirements or other considerations). Again, it is not to be inferred from this discussion that box size is not an important parameter. Depending on circumstances, it may be necessary to select designs outside of the range of values suggested here.

For design purposes, the method outlined above should provide a simple and conservative approach to estimating K_{CB}, knowing the ratio of the of the conflict pipe and the box to the drainline diameter. The hydraulic performance of the conflict box, (ie the loss as a function of flow) can then be computed from Equation 1.

For example, suppose a stormwater drainline with diameter 3 ft is to be installed, conflicting with a 1.2 ft utility pipeline. The elevation of the conflict centerline (S_V) is 0.6 ft above the centerline of the drainline meaning that the bottom of the conflict pipe is 1.5 ft above the invert of the drainline (clearance dimension). Thus the 1 ft clearance rule is satisfied. It is necessary to select a box size and configuration for the junction. The appropriate ratios are $S_V/D_P = 0.2$ and $D_C/D_P=0.4$. Entering Figure 10 (or Appendix B) at S_V/D_P=0.2 and moving up to the D_C/D_P=0.4 correlation, indicates a trial loss factor of 0.38. The performance relationship for these box ratios (Equation 1), rewritten in terms of the flowrate yields

$$h_l = \frac{8KQ^2}{g\pi^2 D_p^4} \tag{5}$$

Inserting numerical values,

$$h_l = 1.18x10^{-4}Q^2 \tag{6}$$

(where the loss is in feet and the flowrate is in cfs). Further assume that the maximum velocity in the drainline is expected to be 10 fps, for a discharge of 70.7 cfs, then the maximum loss would be estimated at 0.59 ft. From this information (and the system layout) the hydraulic gradeline for the system can be constructed to estimate the elevation in the box.

If this loss can be tolerated in the system design, then it remains to choose a box configuration. The smallest box width is set by the drainline diameter (3 ft). Consider the choice of a square box (4x4 ft), so that D_B/D_P=1.33 and D_C/D_B=0.3. This box ratio was tested with a range of conflict ratios including the current values (the loss factor can be confirmed approximately by direct examination of Figure 5a). The conflict diameter-box combination would allow an access opening for maintenance at each side of 1.4 ft. The 4 ft square box then appears to be a reasonable, economic choice. It is also possible that a smaller rectangular box might be acceptable or a larger box desirable (for example to improve access). To illustrate, the selection of a round box with D_B/D_P=2 (6 ft diameter) is still approximately 0.4, confirmed by averaging between from Figures 7b and 7c.

Note that by going to a larger box, the loss factor is not significantly changed. As noted previously, the dependence of loss factor on the various configuration parameters is complex and the difference between these two box configurations, even though substantial, does not result in a large change in the interference of the jet by the conflict. To change the maximum loss expected for the same loss factor would mean selecting a larger pipeline diameter so that the maximum kinetic energy would be reduced. Suppose a 3.5 ft diameter pipe was chosen for the same flow, reducing the maximum expected velocity to 7.35 fps. Selecting a 4x5 ft rectangular box gives D_B/D_P=1.14, S_V/D_P = 0.1 and D_C/D_P=0.34. Again from Figure 10 estimate the loss at 0.38 (no change, however the numerical coefficient in Equation 6 must be recomputed).

The losses are reduced to 0.32 ft (assuming the same maximum flowrate) at the cost of a larger drainline, however.

EXTENDED STUDY OF ALTERNATIVE CONFIGURATIONS

Sumped junction boxes

As part of the current research program, several alternative designs for conflict junction boxes were investigated. Part of this effort focused on sumped boxes (not studied in the previous investigation), wherein the bottom of the box is dropped so that silt and trash may accumulate. Under current rules [1], sumped manholes may be installed, but are permitted only if allowances are made to correct for the losses in a blocked condition. It is specified that larger boxes should be selected in this case. One potential advantage of sumped boxes is that dropping the bottom of the box lower than the invert of the drain line gives a larger clearance beneath the conflict pipe, and it is possible that losses could actually be reduced. Furthermore, it may be possible to lower the conflict relative to the storm water pipe. More of the main flow across the conflict would be interrupted if the conflict were centered in on the storm line, but lowering the pipe below the center of the drainline could reduce interference. In this case, more water would likely flow over the top of the conflict. It is also noted that in conventional junction boxes benching or channelizing the flow near the box bottom can be beneficial in reducing losses. The goal of this portion of the study was to examine the following issues:

1. The loss associated with sumping, assuming conventional placement of the conflict.

2. The loss incurred when the conflict is lowered below normal clearance dimensions.

3. The potential advantages of guiding the flow (with low losses) through the sumped region of the box when the conflict obscures a substantial part of the drainline.

Accordingly, a series of experiments were conducted with a square box of D_B/D_P= 1.75, for which a good base of information for conventional designs is available. The first experiment tested a box with a bottom dropped by the diameter of the inlet pipe. Secondly, a section of circular pipe was added to simulate the effect of filling the corners at the bottom. Finally, two side pieces were added to the circular portion to simulate benching. (Figure 11) The same flow conditions and conflicts as the base case were tested in all other cases. The results for this portion of the investigation are shown in Figure 12.

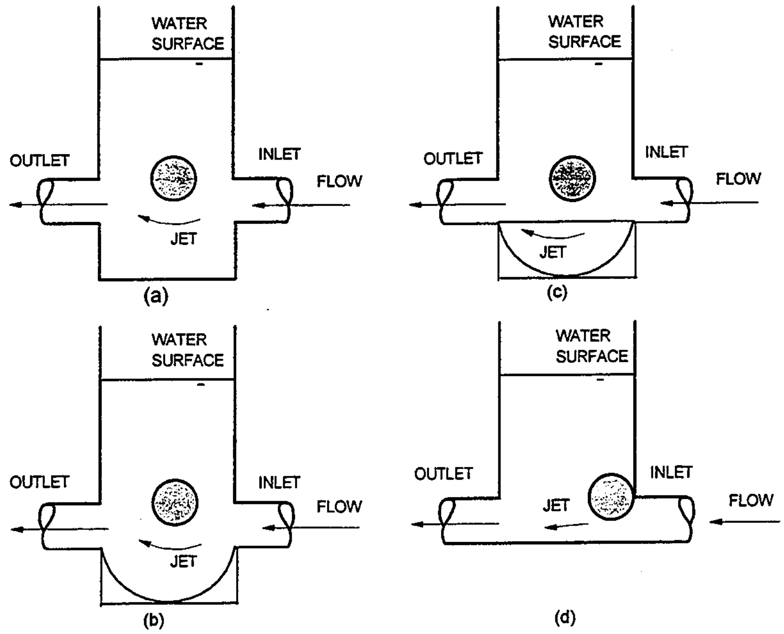

Figure 11: Square box modifications tested; a) conventional sumped box, b) flow deflectors, c) flow deflection with side guidance, d) horizontal reposition of pipe in conventional box.

Figure 12 shows the performance of the modified designs with conflicts of 0.5 ft (D_C/D_P=1.10) compared to similar data for the conventional, flush bottom design. To project the loss at S_V/D_P =0.0 (centerline), data from Reference 2 was introduced for the conventional design. In these experiments, the conflict position was varied over a much larger vertical range. Testing of sumped boxes (0.5 ft drop, Type a, b, and c) with conflicts indicated that this style performed better than the conventional design, although the loss factor was large due to the large conflict pipe. At higher positions (little interaction with the conflict) there is little or no difference in performance for the sumped boxes compared to the nonsumped configurations. The maximum loss factor occurs when the conflict is centered (K~1.5). As the elevation of the conflict pipe is further reduced the loss factor once again decreases, indicating that very large conflicts could be accommodated at lower than inlet pipe centerline.

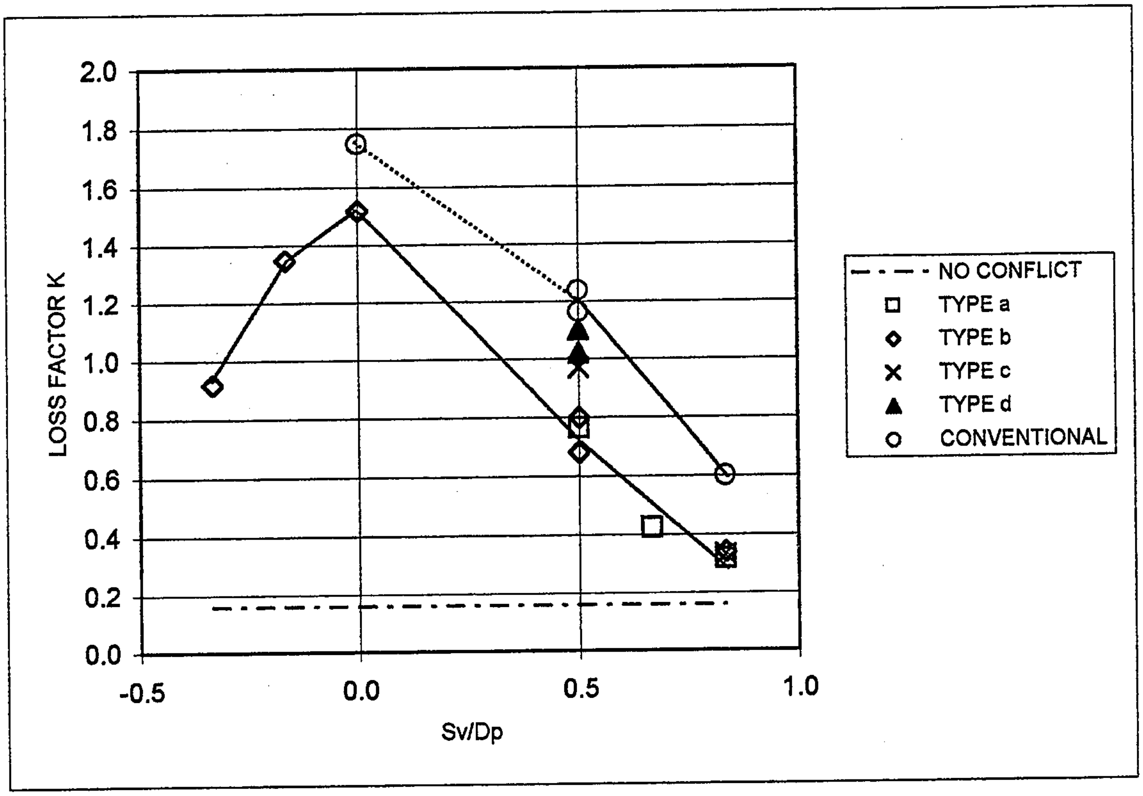

Figure 12: Effect of dropped bottom on the losses for a square box (D_B/D_P=1.75 D_C/D_P=1.10) without the normal bottom clearance restriction, as shown in Figure 11. Trend lines are not computed fits. Data for Type d modifications have been superposed (solid triangles).

Data for boxes with streamlining along the direction of flow (Figure 11b) were very similar to sumped boxes with no streamlining (Figure 11a) and only one line representing Type a, b and c has been drawn in Figure 12 to indicate these trends. the guided (benched, Figure 11c) bottom installed in the sumped box appeared to give slightly higher losses than the other modifications but still less than conventional configurations. The results reported here for Types a, b and c represent a probable worst case (because of the large conflict diameter), and smaller conflicts would be expected to result in lower loss factors.

Whether or not sediment and trash would reduce this advantage is not known at this time. In a situation where the conflict pipe was set below the centerline in a sumped box and the depressed bottom filled with sediment, the resulting configuration would resemble a bump along the bottom with flow over the top of the conflict. Results suggest that this geometry would be tolerable, but beyond the data reported here (and in [2] for conflicts with trash lodged underneath) no loss values can be given.

Results for horizontally offset conflicts

The underlying concept of this design is to position the conflict (in a conventional box) so that the pipe touches the front upstream wall of the box (cf Figure 11d), in effect closing off the path over the top of the conflict and instead forcing all flow under the pipe, much like a nozzle. If the jet does not spread excessively, much of the kinetic energy of the emerging flow will be retained and recaptured as the flow reenters the drainline exiting from the box. A decision was made to briefly explore this idea as a means of further reducing losses, while allowing a relatively large conflict. Two values for the loss factor were measured, one for a conflict pipe positioned so that it touched the inlet wall, and the other a short distance away (0.083 ft). Both of these data have been placed on Figure 12. The result show a slight decrease in loss but not sufficient to warrant adoption of this design without further investigation.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions drawn from the findings of the research reported here may be summarized as follows:

1. The losses encountered at a conflict junction box may be adequately represented in terms of a conventional loss factor. As would be expected, losses increase with larger conflict size and as the conflict pipe is positioned closer to the center of the drainline. As in [2], it is significant that in no situation examined did the loss factor become much larger than 1.5. Therefore an explanation for the loss mechanism in terms of jet disruption (stagnation of the inflow and a redevelopment at the exit) appears to be consistent with the data (the loss factor could be substantially greater for configurations where the inflow or outflow were partially blocked). It is recommended that if possible, design selections are made which restrict the loss coefficient to a magnitude less than one.

2. Over the range of parameters (S_V/D_P, D_C/D_P, D_B/D_P) tested in this investigation, the best correlation of loss was made with S_V/D_P as the independent parameter and D_C/D_P as a secondary parameter. Box size was relatively unimportant over the range tested here. Results for rectangular boxes appear to fit this correlation, when the dimension

along the flow line is used as a measure of box size. A design method has been presented based on this correlation. It is believed that this method will conservatively predict losses and result in an economic choice of size for the box. It is recommended that this method be used in preference to the correlations presented in [2], because those correlations were developed exclusively for centered conflicts in boxes somewhat larger than are found in practice. No further observations about the possible existence of a loss minimum with box size (as discussed in Reference 2) could be made

Factors influencing the range of applicability of these conclusions have been identified and include velocity and submergence as well as box and conflict size. Perhaps the most important is submergence, especially if the flow shallow and supercritical. In this circumstance the presence of a conflict may have an entirely different effect on the flow. Also it is noted that the selection of round boxes may be less economical, since larger diameters are generally required to accommodate the drain pipe.

3. Results for simple two port boxes with no conflicts have been extended to lower values of the parameter D_B/D_P, and it was found that losses observed were somewhat lower than previous correlations would indicate. Use of the correlation from [10] given in Equation 3 is conservative however.

4. It was found that the condition of the pipe end entering round boxes was not particularly important in determining loss for the box, with or without conflict. This result suggests that fairing the pipe end may not be effective in reducing losses at the box exit, except at the very highest loss factors.

5. It is recommended that the currently imposed clearance rule be maintained to forestall trash accumulation. It may be desirable to add a safety factor to account for blockage by trash or sediment. During the course of this investigation, it was found that lower loss factors could be achieved for sumped designs and that if circumstances required a conflict position lower than the clearance rules permit, this design choice might be acceptable.

6. Tests conducted to determine the possible benefits of moving the conflict horizontally were not promising and this approach cannot be recommended.

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APPENDIX A: Summary of loss coefficients reduced from original data
(Data omitted in correlations shown in Figure 10 are shaded)

SQUARE BOXES

DC/DB	DB/DP	DC/DP	SV/DP ->	0.22	0.40	0.58	0.75	1.10	1.44
0.33	1.20	0.40	0.00		0.539				
0.33		0.40	0.33		0.297				
0.33		0.40	0.50		0.189				
0.49		0.58	0.00			0.851			
0.49		0.58	0.50			0.294			
0.49		0.58	0.67			0.134			
0.26	1.50	0.40	0.08		0.494				
0.26		0.40	0.50		0.271				
0.39		0.58	0.25			0.632			
0.39		0.58	1.00			0.128			
0.50		0.75	0.25				0.933		
0.50		0.75	0.67				0.250		
0.50		0.75	1.00				0.128		
0.23	1.75	0.40	0.17		0.436				
0.23		0.40	0.50		0.257				
0.33		0.58	0.33			0.598			
0.33		0.58	0.50			0.357			
0.33		0.58	0.67			0.203			
0.43		0.75	0.33				0.875		
0.43		0.75	0.67				0.283		
0.43		0.75	0.83				0.170		
0.63		1.10	0.50					1.261	
0.63		1.10	0.83					0.603	
0.14	2.80	0.40	0.33		0.558				
0.14		0.40	0.50		0.447				
0.21		0.58	0.33			0.723			
0.21		0.58	0.50			0.431			
0.21		0.58	0.67			0.269			
0.27		0.75	0.67				0.332		
0.27		0.75	0.83				0.260		
0.39		1.10	0.67					0.607	
0.39		1.10	0.83					0.452	
0.39		1.10	1.00					0.269	
0.51		1.44	0.67						0.810
0.51		1.44	0.83						0.683
0.51		1.44	1.17						0.268

APPENDIX A: Summary of loss coefficients reduced from original data
(Data omitted in correlations shown in Figure 10 are shaded)

RECTANGULAR BOXES

DC/DB	DB/DP	DC/DP	SV/DP ->	0.22	0.4	0.58	0.75	1.1	1.44
0.32	0.68	0.22	-0.17	0.259					
0.32		0.22	0.42	0.132					
0.32		0.22	0.58	0.036					
0.58		0.40	0.00		0.529				
0.58		0.40	0.42		0.221				
0.58		0.40	0.67		0.028				
0.86		0.58	0.00			1.644			
0.86		0.58	0.42			0.462			
0.86		0.58	0.75			0.071			
0.32	0.68	0.22	-0.17	0.289					
0.32		0.22	0.42	0.129					
0.32		0.22	0.58	0.017					
0.58		0.40	0.00		0.515				
0.58		0.40	0.42		0.211				
0.58		0.40	0.67		0.020				
0.86		0.58	0.00			1.950			
0.86		0.58	0.42			0.399			
0.86		0.58	0.75			0.023			
0.22	1.00	0.22	-0.17	0.249					
0.22		0.22	0.42	0.195					
0.22		0.22	0.58	0.060					
0.40		0.40	0.00		0.430				
0.40		0.40	0.42		0.242				
0.40		0.40	0.67		0.050				
0.58		0.58	0.00			0.916			
0.58		0.58	0.42			0.359			
0.58		0.58	0.75			0.064			

APPENDIX A: Summary of loss coefficients reduced from original data
(Data omitted in correlations shown in Figure 10 are shaded)

ROUND BOXES

DC/DB	DB/DP	DC/DP	SV/DP ->	0.22	0.4	0.58	0.75	1.1	1.44
0.30	1.33	0.40	0.33		0.321				
0.30		0.40	0.50		0.160				
0.44		0.58	0.33			0.639			
0.44		0.58	0.50			0.249			
0.44		0.58	0.67			0.110			
0.56		0.75	0.67				0.116		
0.24	1.67	0.40	0.00		0.426				
0.24		0.40	0.17		0.384				
0.24		0.40	0.50		0.158				
0.35		0.58	0.33			0.443			
0.35		0.58	0.50			0.289			
0.35		0.58	0.67			0.116			
0.45		0.75	0.33				0.721		
0.45		0.75	0.67				0.230		
0.45		0.75	0.83				0.078		
0.66		1.10	0.50					0.736	
0.66		1.10	0.67					0.322	
0.66		1.10	0.83					0.212	
0.15	2.67	0.40	0.17		0.449				
0.15		0.40	0.33		0.501				
0.15		0.40	0.67		0.227				
0.22		0.58	0.33			0.616			
0.22		0.58	0.50			0.381			
0.22		0.58	0.67			0.259			
0.28		0.75	0.33				0.670		
0.28		0.75	0.50				0.499		
0.28		0.75	0.67				0.376		
0.28		0.75	0.83				0.229		
0.41		1.10	0.67					0.663	
0.41		1.10	0.83					0.477	
0.41		1.10	1.00					0.234	

APPENDIX B: Reproduction of Figure 10 as a design graph (data points suppressed).