

# Head Losses in Pipe Fittings with Stepped Contractions and Expansions

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## ABSTRACT

Many pipe fittings manufactured for use in small diameter plastic pipe systems produce joints with several closely spaced contractions and expansions. Doubts about the effect of these steps on head losses through such joints led to the testing of several types of fittings designed for use with polyethylene piping. The head loss results are presented together with values computed using published data for contractions and expansions of simpler geometry. The results are interpreted in terms of boundary layer changes within the joints.

## INTRODUCTION

Many compression fittings for polyethylene pipes incorporate internal sleeves which locally reduce the diameter of the flow cross-section. The geometry of the passage is frequently complex as the assembly often involves a series of stepped contractions and expansions.

It is possible to estimate the head losses through contractions and expansions using data published in reference books such as that by Miller (1978). However, because of the uncertainty of the interactions between the boundary layer changes which may be generated by the multiple steps in diameter in some fittings, such estimates may involve considerable error. When head loss comparisons were required for some commercial fittings it was decided by the authors that measurements on actual fittings were required. Following analysis of the results of tests on several fittings it was decided to carry out experiments with constrictions of simpler geometry to produce some more basic data. It was hoped that this data would clarify the conditions under which head losses through a series of expansions and contractions could be calculated with sufficient accuracy by simply adding losses predicted for individual steps.

## FITTINGS TESTED

Flow sections through some actual fittings tested are shown in Figure 1. Some of the fittings are symmetrical, for example unions to join polyethylene pipes of the same diameter. Others, for example polyethylene to galvanised pipe unions, are asymmetrical and the head loss may depend on the direction of flow. The more complex shapes result from the use of internal sleeves to adapt external couplings designed for metric sized pipes of constant outside diameter for use with imperial sized pipes of constant inside diameter. The flow passages shown in Figure 1 are drawn in the correct proportions for unions for 1 inch nominal diameter pipes. Unions for 2 inch pipes were also tested. Length to diameter ratios differed from those of the 1 inch unions. A summary of the principal geometric data is given in Table 1.

The simpler constrictions tested are shown diagrammatically in Figure 2. Sleeves with the range of lengths and internal diameters shown were fitted in turn into a 2 inch nominal diameter polyethylene pipe-line at a joint by pushing them into the pipes until the pipe ends butted against the flange. The sleeved joint made in this way with a plain smooth bore was

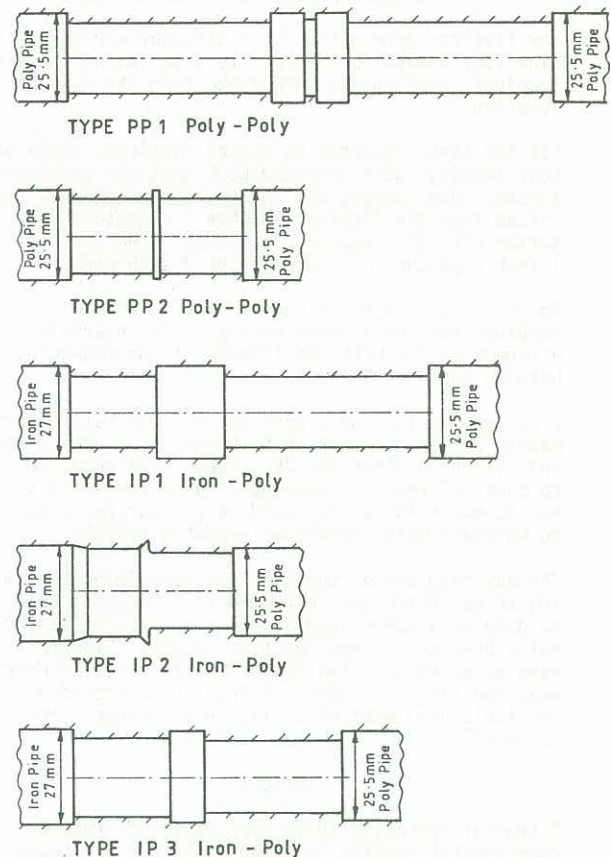
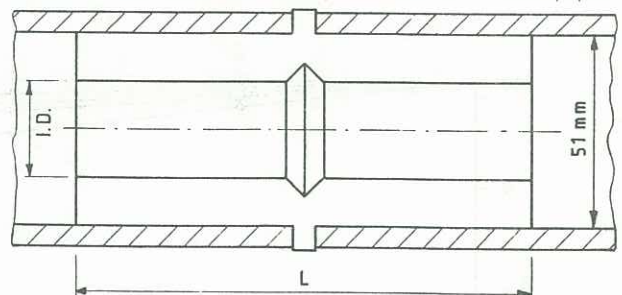


Fig 1: Flow passages through unions for 1 inch pipes.



## NOTES

- (i)  $L = 100, 150, 200, 250, 300$  mm
- (ii) I.D. = 25, 35, 45 mm with each  $L$  value
- (iii) Bore either plain, grooved  $10\text{ mm} \times 5\text{ mm}$  deep V as shown or grooved  $10\text{ mm} \times 5\text{ mm}$  deep U

Fig 2: Dimensions of plain and grooved sleeves.

considered to have the simplest geometry it would be possible to produce in a practical connection. This shape was tested to

- (i) give minimum practical values of head loss with which losses for other more complex flow passages could be compared.

- (ii) provide verification of the procedure of obtaining a total head loss by adding contraction and expansion losses taken from Miller (1978) for several values of the ratio of diameter to length between the contraction and expansion.

After tests had been carried out on the smooth-bore sleeves, notches were cut inside the sleeves at the mid-points to simulate the effect of a local increase in diameter at the junction between the pair of sleeves used in most compression unions. The sleeves may be bevelled or rounded or may not butt closely, thus producing an annular groove in the flow passage. Both V-shaped and rectangular grooves were used as described in Figure 2.

#### EXPERIMENTAL EQUIPMENT AND PROCEDURE

The fittings were set up in a straight horizontal pipeline long enough to incorporate a series of pressure tappings upstream and downstream from the fitting location.

For the tests reported on actual fittings, three or four tappings were provided both upstream and downstream. One tapping was located 1 pipe diameter upstream from the fitting, another 2 diameters downstream with the remainder spaced at 0.9m intervals for 1 inch pipe and 1m intervals for 2 inch pipe.

For the tests on the sleeves shown in Figure 2, six tappings were positioned evenly at 3m intervals over a length of 15m with the fitting at the mid-point between tappings 3 and 4.

Pressure tappings were made by drilling holes approximately 2mm in diameter at both ends of a pipe diameter and attaching clear 8mm PVC tubes. The tubes were led to banks of vertical manometer tubes connected at the top to manifolds which could be pressurised with air to maintain water levels at readable heights.

The upstream end of the pipeline containing the fitting to be tested was connected to a constant head tank to provide a water supply. Flow was controlled by a valve downstream from the test length. Flow rates were measured by weighing the water collected over measured time intervals. Velocities achieved with the available head were generally in the range 1 to 2.5 m.s<sup>-1</sup>.

#### RESULTS

A typical hydraulic grade plot prepared from the experimental results is shown in Figure 3. Local depression of the piezometric head just downstream

from the fitting is not shown since no downstream tapping was situated close enough to the fitting in this case. The tapping located 2 pipe diameters downstream from the commercial fittings tested showed a marked drop in pressure, indicating they were in the zone of influence of the higher velocity jet issuing from the restriction. Since close downstream tappings were not helpful in determining the overall additional head loss caused by the fitting, they were not used in the subsequent tests on the sleeves.

Extrapolation of the straight lengths of hydraulic grade line to the fitting location allows the additional head loss  $H_L$  introduced to the pipeline by a fitting to be determined from the equation

$$H_L = \frac{\Delta p}{\rho g} + \left( \frac{V_1^2}{2g} - \frac{V_2^2}{2g} \right) \quad (1)$$

where  $\Delta p/\rho g$  is the step between the extrapolated hydraulic grade lines and  $V_1^2/2g$  and  $V_2^2/2g$  are the velocity heads in the upstream and downstream sections of the pipeline.

The slopes of the hydraulic grade lines were compared with those predicted by the Darcy equation using the Colebrook-White equation for the friction factor. This check was found to produce very good agreement between actual and expected pipe friction losses. It was concluded that the pressure tappings and manometers were functioning correctly and that the measured steps in the hydraulic grade lines would provide reliable data on head losses caused by the fittings under test.

Typical plots of head loss versus flow rate for the commercial unions tested are given in Figure 4. The substantial differences in head loss through equivalent fittings of differing design are evident. Detailed results of all the tests performed could not be accommodated in this paper. They are available from the senior author on request. Head loss coefficients calculated from the results are given in the following section.

#### ANALYSIS OF RESULTS

Values of loss coefficient  $K_L$  in the equation

$$H_L = K_L \frac{V_1^2}{2g} \quad (2)$$

with  $V_1^2/2g$  the velocity head in the pipe upstream from the fitting, were calculated for all test runs. Loss coefficients were also estimated, using the data given in Figures 14.14 and 14.15 of Miller (1978), for all the sleeves defined by Figure 2 and for the commercial unions.

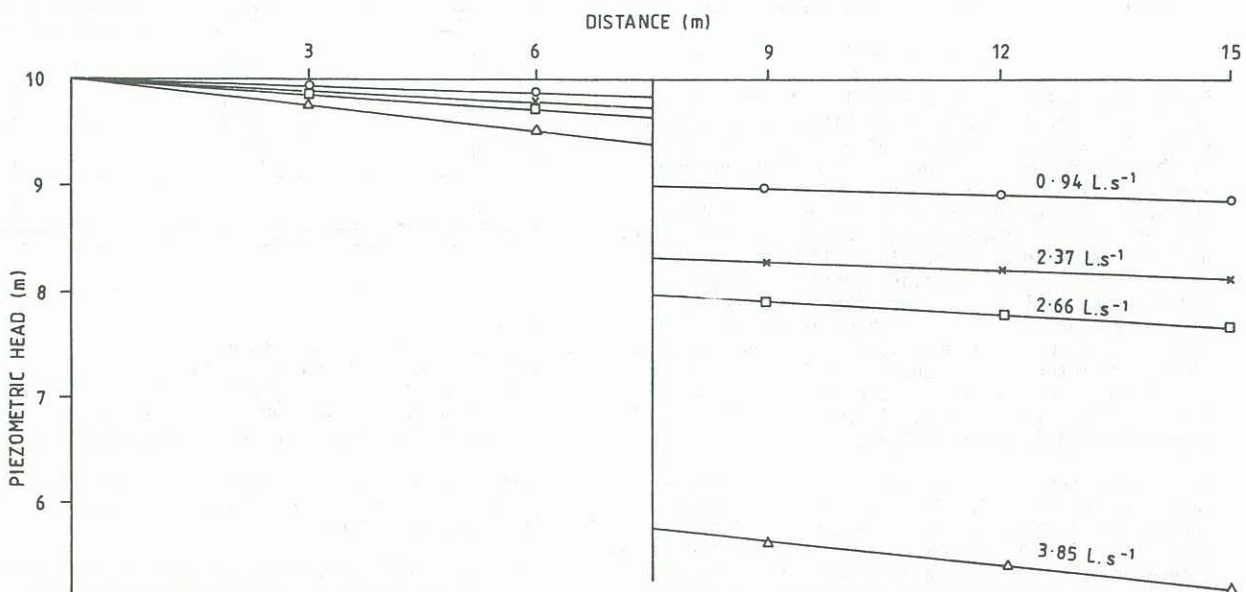


Fig 3: Typical hydraulic grade line plot - 300mm x 25mm plain-bore sleeve.

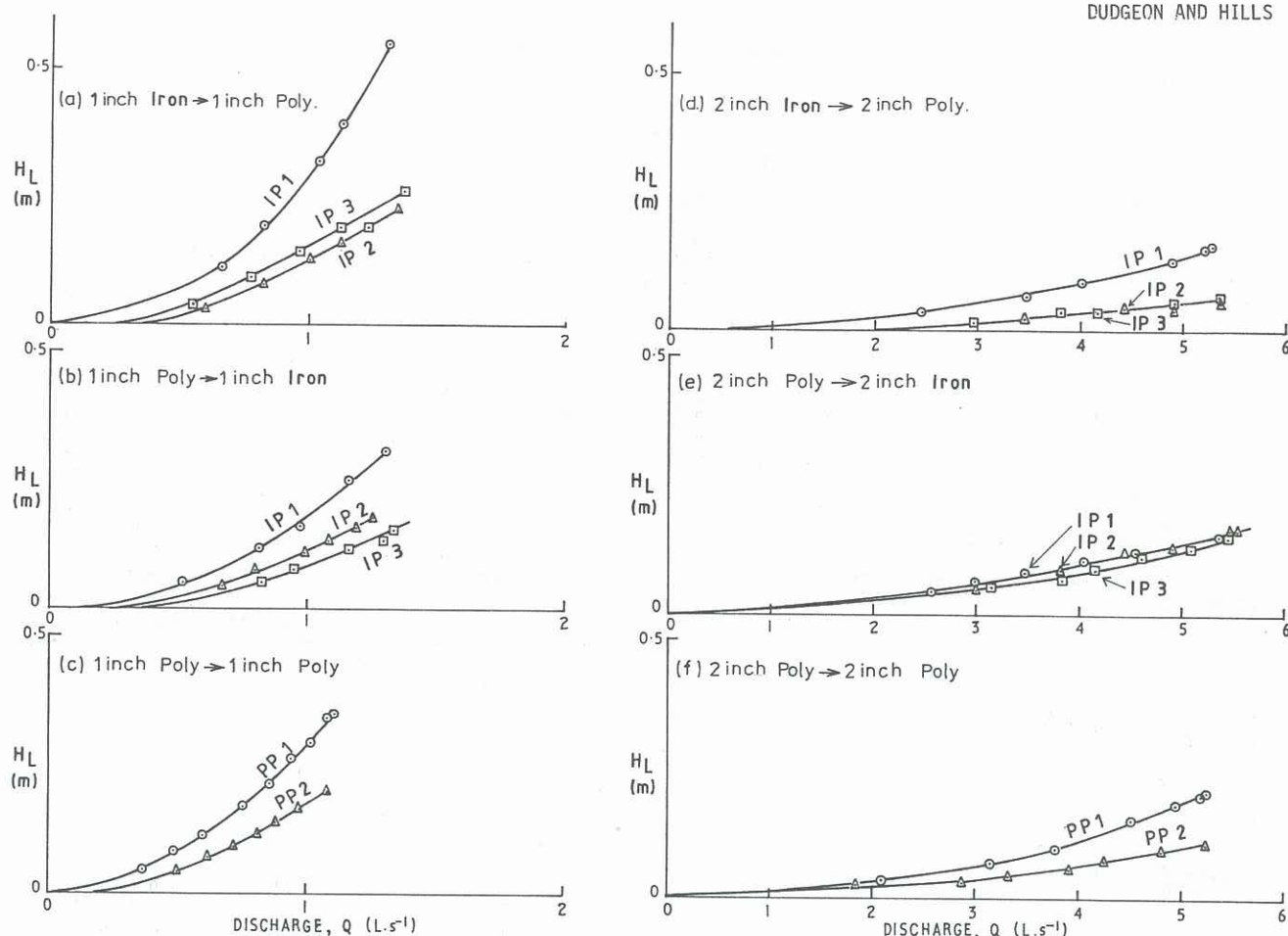


Fig 4: Head losses through pipe unions.

Experimentally determined and estimated loss coefficients are given in Tables 2 to 4. The measured coefficients were found to be largely independent of Reynolds number for the range of velocities used. In practice, normal operating velocities would be in this range. The mean loss coefficients listed were obtained from head losses measured for five or more flow rates.

For the sleeves, the maximum variation between the coefficient for a particular flow rate and the average shown in Table 2 was of the order of 10 per cent except for the 45mm diameter bore sleeves. The significant dependence of loss coefficient on Reynolds number in this case is demonstrated by the data given in Table 3.

For sleeves of small internal diameter the main factor influencing the loss coefficient appeared to be the ratio  $L/D_{min}$ . Figure 5 is a plot of this dependence for several of the sleeves.

Table 1: Dimensions of passages in pipe unions.

Type	Pipes Joined		Flow Passage			
	Type	Inside Diameters mm	Length L mm	Diameter in		L/D <sub>min</sub>
				Iron mm	Poly mm	
PP1-1"	Poly-Poly	25.5-25.5	145	-	19.8	7.3
PP2-1"	Poly-Poly	25.5-25.5	50	-	20.8	2.4
IP1-1"	Iron-Poly	27.0-25.5	105	20.5	20.0	5.3
IP2-1"	Iron-Poly	27.0-25.5	25	25.0	20.8	1.2
IP3-1"	Iron-Poly	27.0-25.5	80	23.0	21.0	3.8
PP1-2"	Poly-Poly	51.0-51.0	215	-	43.2	5.0
PP2-2"	Poly-Poly	51.0-51.0	70	-	43.8	1.6
IP1-2"	Iron-Poly	52.9-51.0	145	43.9	43.2	3.4
IP2-2"	Iron-Poly	52.9-51.0	35	50.0	43.8	0.8
IP3-2"	Iron-Poly	52.9-51.0	105	46.8	44.3	2.4

## DISCUSSION

Many polyethylene pipelines consist of relatively long lengths of pipe connected by a few fittings. In these cases the types of fitting used and a knowledge of the head loss coefficients are of little consequence to the hydraulic design of the pipeline. However, an increasing number of pipelines related to intensive irrigation use large numbers of fittings. Minimisation of head losses through these becomes important. The data provided in this paper may be of assistance in the design and selection of fittings which reduce head losses as far as possible. The results of tests on the simpler sleeves may also be of more general interest in the fluid mechanics of closed conduit flow.

Head loss coefficients estimated for flow passages through commercial unions do not agree well with estimates based on abrupt contraction and expansion coefficients except for unions with relatively simple internal geometry. It is clear from the data provided

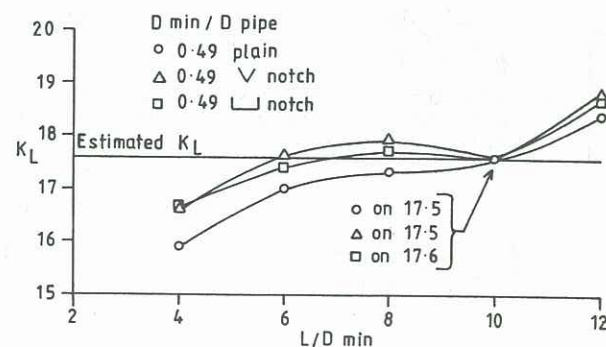


Fig 5: Variation of head loss coefficient with sleeve length.

Table 2: Head loss coefficients for pipe unions

Union	$D_{\min}/D_{\text{pipe}}$	$L/D_{\min}$	Flow Direction	Range of $R \times 10^{-4}$	Head Loss Coefficient $K_L$		
					Range	Mean	Estimate
PP1 - 1 inch	0.78	7.3	Poly→Poly	5.5 - 1.9	1.5 - 1.7	1.5	2.7
PP2 - 1 inch	0.82	2.4	Poly→Poly	5.4 - 2.5	0.9 - 0.8	0.9	0.8
IP1 - 1 inch	0.78	5.3	Iron→Poly	6.5 - 3.3	2.1 - 1.7	1.9	3.0
IP2 - 1 inch	0.82	1.2	Poly→Iron	6.5 - 2.6	0.9 - 1.0	0.9	2.3
			Iron→Poly	6.7 - 3.0	0.8 - 0.6	0.8	1.0
IP3 - 1 inch	0.82	3.8	Poly→Iron	6.3 - 3.4	0.6 - 0.5	0.6	0.9
			Iron→Poly	6.9 - 2.8	0.9 - 0.8	0.9	1.5
			Poly→Iron	6.7 - 4.1	0.4 - 0.4	0.4	1.1
PP1 - 2 inch	0.85	5.0	Poly→Poly	9.4 - 8.2	0.6 - 0.6	0.6	1.2
PP2 - 2 inch	0.86	1.6	Poly→Poly	9.5 - 3.3	0.3 - 0.3	0.3	0.5
IP1 - 2 inch	0.85	3.4	Iron→Poly	13.2 - 6.2	0.6 - 0.5	0.6	1.4
			Poly→Iron	9.7 - 4.6	0.4 - 0.5	0.5	1.1
IP2 - 2 inch	0.86	0.8	Iron→Poly	13.4 - 8.7	0.2 - 0.2	0.2	0.2
			Poly→Iron	10.0 - 5.4	0.4 - 0.5	0.5	0.2
IP3 - 2 inch	0.87	2.4	Iron→Poly	13.4 - 7.4	0.2 - 0.2	0.2	0.8
			Poly→Iron	9.9 - 5.7	0.4 - 0.4	0.4	0.6

Table 3: Head loss coefficients for sleeves

Sleeve	$\frac{D_{\min}}{D_{\text{pipe}}}$	$\frac{L}{D_{\min}}$	Loss Coefficient $K_L^*$	
			Actual	Estimate
100 x 25	0.49	4.0	15.9	17.6
150 x 25		6.0	17.0	
200 x 25		8.0	17.3	
250 x 25		10.0	17.5	
300 x 25		12.0	18.9	
100 x 25 V	0.49	4.0	16.6	17.6
150 x 25		6.0	17.6	
200 x 25		8.0	17.9	
250 x 25		10.0	17.5	
300 x 25		12.0	19.3	
100 x 25 □	0.49	4.0	16.7	17.6
150 x 25		6.0	17.4	
200 x 25		8.0	17.7	
250 x 25		10.0	17.6	
300 x 25		12.0	19.2	
100 x 35	0.69	4.0	2.3	2.8
200 x 35		8.0	2.5	
250 x 35		10.0	2.7	
300 x 35		12.0	2.6	
100 x 35 V	0.69	4.0	2.4	2.8
200 x 35		8.0	2.7	
250 x 35		10.0	2.7	
300 x 35		12.0	2.7	
100 x 45	0.45	4.0	See Table 4	0.23
150 x 45		6.0		
200 x 45		8.0		
250 x 45		10.0		
300 x 45		12.0		

\*Note:

- (i) Actual values of  $K_L$  are for an approximate range of approach Reynolds number  $R = 0.5 \times 10^5$  to  $2.2 \times 10^5$ .
- (ii) Estimated values of  $K_L$  were obtained by adding losses for one contraction and one expansion in series assuming no interaction.

that there is scope for more rational design of some fittings, the aim being to minimise the reduction in flow cross section, eliminate unnecessary grooves and provide tapered or rounded contractions. The fittings with internal sleeves used with pipes of constant inside diameter are clearly inferior to those completely external fittings which are available for use with pipes of constant outside diameter.

One interesting point which emerges from the results of tests on internal sleeves is the effect of length between the contraction and expansion, as shown in Figure 5. For short lengths, the coefficient is lower than expected, presumably because the length is insufficient for the boundary layer to become fully attached after separation at the contraction, thus reducing the loss at the contraction. As the length increases, friction loss in the high velocity developing flow in the sleeve adds significantly to the expansion and contraction losses causing the coefficient to rise above the estimated value. The central notch increases the head loss except at some critical  $L/D$  ratio where the effect becomes insignificant. This is assumed to be related to the point of re-attachment of the boundary layer following the contraction. Further visualisation experiments are required to confirm this.

For simple series contractions and expansions it can be concluded that addition of losses predicted from data given by Miller (1978) is accurate except when

- the intervening length is too short to allow boundary layer re-attachment or so long that additional friction losses must be taken into account.
- the reduction in diameter through the sleeve is small. In this case Reynolds number plays a significant role in determining the loss coefficient, presumably because of its effect on the extent of the separation zones downstream from the contraction and the expansion.

## REFERENCE

Miller, D.S. (1978) *Internal Flow Systems*, British Hydromechanics Research Association.

Table 4: Effect of Reynolds number on head loss coefficient for 45mm bore sleeves

$L = 100\text{mm}$		$L = 150\text{mm}$		$L = 200\text{mm}$		$L = 250\text{mm}$		$L = 300\text{mm}$	
$R \times 10^{-5}$	$K_L$	$R \times 10^{-5}$	$K_L$	$R \times 10^{-5}$	$K_L$	$R \times 10^{-5}$	$K_L$	$R \times 10^{-5}$	$K_L$
2.2	0.21	2.3	0.22	2.2	0.27	2.1	0.28	2.1	0.40
1.9	0.21	1.4	0.24	1.6	0.21	1.2	0.25	1.6	0.33
1.3	0.13	1.0	0.21	1.1	0.16	0.8	0.27	0.9	0.15
0.9	0.12	0.7	0.10	0.6	0.07	0.4	0.00	0.7	0.11