

Analysing Engineering Approximations in Head Losses through Pipe Bends

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ABSTRACT: If Engineering Science is all about accuracy why are approximations sometimes used during design calculations? The analysis presented here attempts to show why approximations in designs should be avoided where accurate measurements are possible. Case in point, how calculation of Head Losses through pipe bends following usual approximations jeopardise the quality and reliability of a network. In this paper, comparison of calculation of Resistance Coefficient (K) values through commonly practiced procedure v/s computation of exact values of resistance coefficient using Mathcad software is made to assess the differences between the measured Head Losses and to determine the implications of such differences on field performance of conveyance networks. The results from the analysis indicates that commonly undertaken practice to find resistance coefficients leads to deteriorated pump efficiency and ineffective working.

KEYWORDS: Engineering Approximations, Head Losses, Miter Bends, Resistance Coefficient (K), Mathcad, Regression Analysis, Problem Statement: Computation of Head Losses through Pipe Bends.

I. INTRODUCTION

Approximations have always been an indispensable process in Engineering Science as sometimes it becomes impossible to make perfectly accurate calculations. Being actively involved in the detailed engineering of Water Infrastructure Works, it is not unusual to come across some peculiar projects which challenges to apply mathematical core concepts to the traditional design practices. One such project, a 30 km long mild steel water conveyance line passing through a residential suburb. Where owing to the area topography and road arrangements an erratic conveyance network with a large number of vertical and horizontal bends was setup with varied angles, as opposed to the standard angles. As a consequence, the minor head losses from bends were comparatively high; to the major head losses due to friction in the conveyance line.

The Resistance Coefficients (K) for bends in Indian Standards and major foreign manuals like American Water Works Association are given only for some standard angles. It is not always possible to cast bend angles as per standardized geometrical relation so, for bends other than the standard angles Engineers commonly take on values of resistance coefficients of standard angles just succeeding the actual encountered bend. This practice estimates head losses with systematic errors resulting in substantial variation leading to a head loss judgement that is too high.

II. LITERATURE REVIEW

Indian Standard Institution, Recommendation for Estimation of Flow of Liquids in Closed Conduits, "Part-II Head Loss in Valves and Fittings", IS: 2951 (Part-II)-1965 (Reaffirmed 2003), for the calculation of head loss through Miter bends gives the values of resistance coefficients for some standard angles [1].

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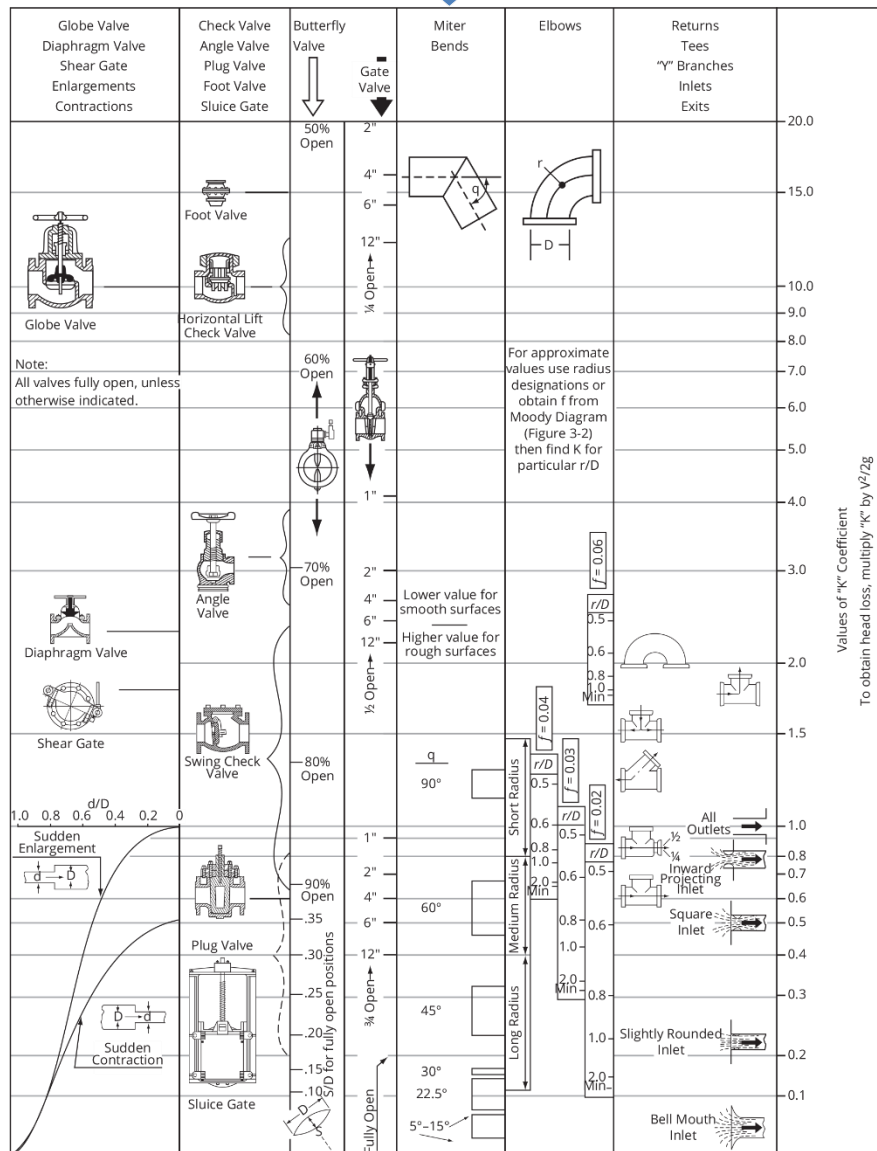
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Table 1. Resistance Coefficients for Miter Bends*

Standard Bends	5°	10°	15°	22.5°	30°	45°	60°	90°
<i>K_{sm}</i> (for smooth surface)	0.016	0.034	0.042	0.066	0.130	0.236	0.471	1.129
<i>K_{ro}</i> (for rough surface)	0.024	0.044	0.062	0.154	0.165	0.320	0.684	1.265

*(Pipe bends made by cutting pipe at an angle and joining)

American Water Works Association, “Steel Pipe – A Guide for Design and Installation”, Manual of Water Supply Practices (M11) Fifth Edition, for the calculation of head loss by flow through pipe bends gives resistance coefficients for Miter bends of some standard angles [2].



(Fig.1). Resistance Coefficients of Valves and Fittings for Fluid Flows

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PTC Mathcad is an Industry Standard calculation software for Engineering Mathematics. Mathcad made is easier to carry out Regression Analysis in statistical modelling, which helped generating a mathematical function to understand the relationship between variables of interest [3].

III. EXPERIMENTAL ANALYSIS

For water conveyance lines with larger diameter and longer distances which predominantly pass through residential suburbs, it was requisite to work out a technique to compute the head losses for bends whose values of resistance coefficients were unaccounted in the standard codes and manuals. Since, they account for appreciable amount of total losses.

(A) Regression Analysis using Mathcad

Standard angles for pipe bends v/s their corresponding resistance coefficients from IS: 2951 (Part-II)-1965 (Reaffirmed 2003) were graphed for smooth (*K_{sm}*) as well as rough (*K_{ro}*) pipe surfaces to perform Regression Analysis, which is mathematical modelling incorporating statistical assessment aimed at creation of desired sample data by which the value of the unknown variables can be determined from the known values of other variables. The regression functions are far less sensitive to factitious data compared to interpolation functions, also it's not necessary that the fitted curve would pass through the available data points.

The objective was obtaining a mathematical function that fits through all data points and to learn how much it could relate to other data-sets.

This was analysed in Mathcad, an Engineering Mathematics Software primarily intended for precise Engineering calculations. Linear, Exponential and Logarithmic models were found to be invalid with irregular fit. The mathematical functions were also analysed comparing the correlation coefficients, which is a statistical measure to judge the proximity of the involved variables. The suitability of the chosen regression was further determined by applying other statistical functions for data analysis.

1. Polynomial Regression in Mathcad

Polynomial Regression function is practical when you have 'set of measured y values' corresponding to 'x values' and you want to fit a polynomial through those y values. Using '*regress*' function in Mathcad, you could use a single polynomial to fit all your data values. The *regress* function lets you fit a polynomial of any order.

The '*loess*' function in Mathcad limits errors by performing a more confined regression. Instead of generating a single polynomial like the *regress* function, *loess* function generates a different 2nd order polynomial depending on your location on the curve. It does this by examining the data in a small vicinity of points where your interest lies.

After analysing various functions, the following 2nd order polynomial curve with regression through the origin came out to be the most suitable and apt for all considered angles having correlation coefficient of 0.98;

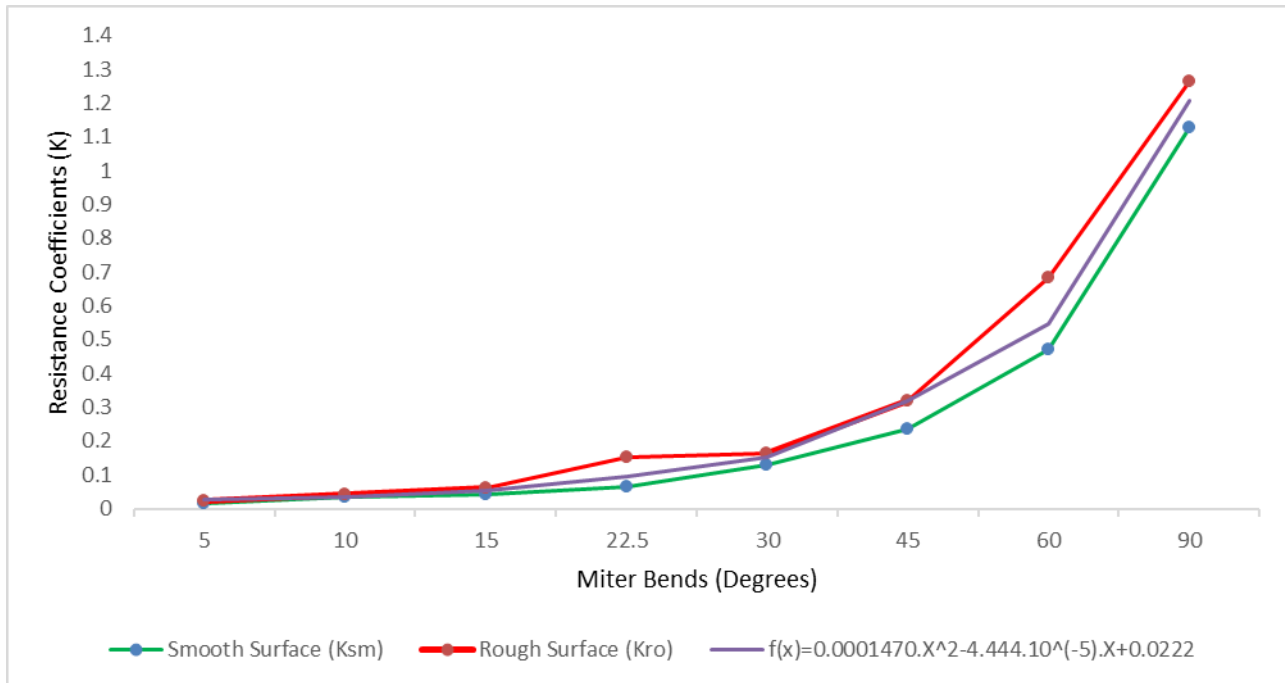
$$f(x) = 0.0001x^2 - 4.4439E.10^{-5}x + 0.0219 \quad (\text{Eq. 1})$$

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(Fig. 2). 2nd Order Polynomial Regression Analysis achieved using Mathcad

The ultimate equation established evaluating the practicability is;

$$f(x) = 0.0001470x^2 - 4.444 \cdot 10^{-5}x + 0.0222 \quad \text{(Eq. 2)}$$

Here, $x = \text{bend angle (degrees)}$

This mathematical function (Eq. 2) could be used to compute the resistance coefficients for every angle in any erratic network arrangement.

(B) Computing the Head Loss

The head loss for bends is computed using Darcy-Weisbach formula which is expressed as;

$$h_L = K \left(\frac{V^2}{2g} \right) \quad \text{(Eq. 3)}$$

Here, $h_L = \text{head loss (m)}$

$K = \text{resistance coefficient}$

$V = \text{mean velocity in conveyance line (m/s)}$

$g = \text{acceleration due to gravity (m/s}^2\text{)}$

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PROBLEM STATEMENT: Computation of Head Losses through Pipe Bends

Consider a smooth mild steel water conveyance line, which is spirally welded having an inside lining of epoxy (This allows for any degree of bend to be achieved in site for fabrication). Assuming average velocity of water in conveyance line to be 1.5 m/s. Using IS 2951 (Part-II) 1965 (Reaffirmed 2003), calculating head losses for standard bends with regards to the values for actual bend following table is obtained:

Head Loss at Bends

Sr. No	Bends Encountered (Degree)	Assuming x20 Similar Bends in the Conveyance Line	‘K’ as per Standard Angles	Head Loss at Bends (m)	Actual ‘K’ as per Equation	Actual Head Loss at Bends (m)
1	6°		0.034 (x20)	0.07806	0.027 (x20)	0.06251
2	7°		0.034 (x20)	0.07806	0.029 (x20)	0.06679
3	8°		0.034 (x20)	0.07806	0.031 (x20)	0.07175
4	12°		0.042 (x20)	0.09643	0.043 (x20)	0.09835
5	14°		0.042 (x20)	0.09643	0.050 (x20)	0.11569
6	17°		0.066 (x20)	0.15153	0.064 (x20)	0.14677
7	20°		0.066 (x20)	0.15153	0.080 (x20)	0.18393
8	26°		0.130 (x20)	0.29847	0.120 (x20)	0.27647
9	34°		0.236 (x20)	0.54184	0.191 (x20)	0.43765
10	36°		0.236 (x20)	0.54184	0.211 (x20)	0.48470
11	38°		0.236 (x20)	0.54184	0.233 (x20)	0.53444
12	40°		0.236 (x20)	0.54184	0.256 (x20)	0.58689
13	42°		0.236 (x20)	0.54184	0.280 (x20)	0.64203
14	49°		0.471 (x20)	1.08138	0.373 (x20)	0.85631
15	51°		0.471 (x20)	1.08138	0.402 (x20)	0.92360
16	55°		0.471 (x20)	1.08138	0.464 (x20)	1.06630
17	57°		0.471 (x20)	1.08138	0.497 (x20)	1.14169
18	65°		1.129 (x20)	2.59209	0.640 (x20)	1.47027
19	67°		1.129 (x20)	2.59209	0.679 (x20)	1.55917
20	75°		1.129 (x20)	2.59209	0.846 (x20)	1.94175
Total			15.83954 m		12.66707 m	

IV. RESULTS AND DISCUSSIONS

1. The aforementioned equation at (Eq.2) could be used to find the relevant values of resistance coefficients for all possible bend angles.
2. From the above analysis it is clearly visible that the head loss judgement was **3.17247m** too high.
3. This difference would have led to selection of pumps with duty head on the higher side. The network at site would obviously had let a lower head, and thus the pumps would have been required to operate lower than their true duty heads.

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V. CONCLUSIONS

1. Evidently, pumps designed at its highest efficiency, which is its duty head would have worked away from their duty point with a lower efficiency. Thus, for the network to perform consistently well such approximations wherever possible must be avoided.
2. Through the analysis presented here, we conclude that the use of effective resistance coefficient values will result in improved pump efficiency and more advantageous working.
3. This equation can be examined opposed to the site figures for the encountered bends by installation of high accuracy differential pressure gauges over the bends.

VI. ACKNOWLEDGEMENTS

I am grateful to all with whom I have had the pleasure to work during this and other comparable projects. Each member at my workplace has provided me extensive personal and professional guidance and taught me a great deal about learning and life in general.

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- [1] Indian Standard Institution, Recommendation for Estimation of Flow of Liquids in Closed Conduits, "Part-II Head Loss in Valves and Fittings", IS: 2951 (Part-II)-1965 (Reaffirmed 2003), pp. 4-9.
- [2] American Water Works Association, "Steel Pipe – A Guide for Design and Installation", Manual of Water Supply Practices (M11) Fifth Edition, pp. 36-39.
- [3] PTC Mathcad Prime 6.0 Software.

BIOGRAPHY



Abhilash Vishwakarma is a Project Engineer accomplished in managing a varied range of projects both within the Public and Private sectors in the Civil Engineering Industry. He is actively involved in detailed engineering for Water Infrastructure Works. As a professional he also blogs on his website thecivilengineeringdaily.wordpress.com about technical aspects of civil engineering works. He is a Rotaractor with active service, Past President of Rotaract Club of RCOEM, Past Zonal Rotaract Representative under District 3030 and an honorary member of The Rotary Club of Nagpur MIHAN Town. When he is not working you will find him spending time with his family and friends. His other personal interests include gardening and long walks.