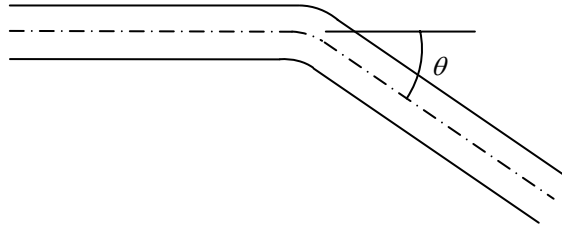


Recommendation for: Bend Losses in Harris County (Revised 12/05/2002)

Goal: To identify a method to account for additional losses (specifically, bend losses) into the HEC-RAS model for use in the TSARP study.

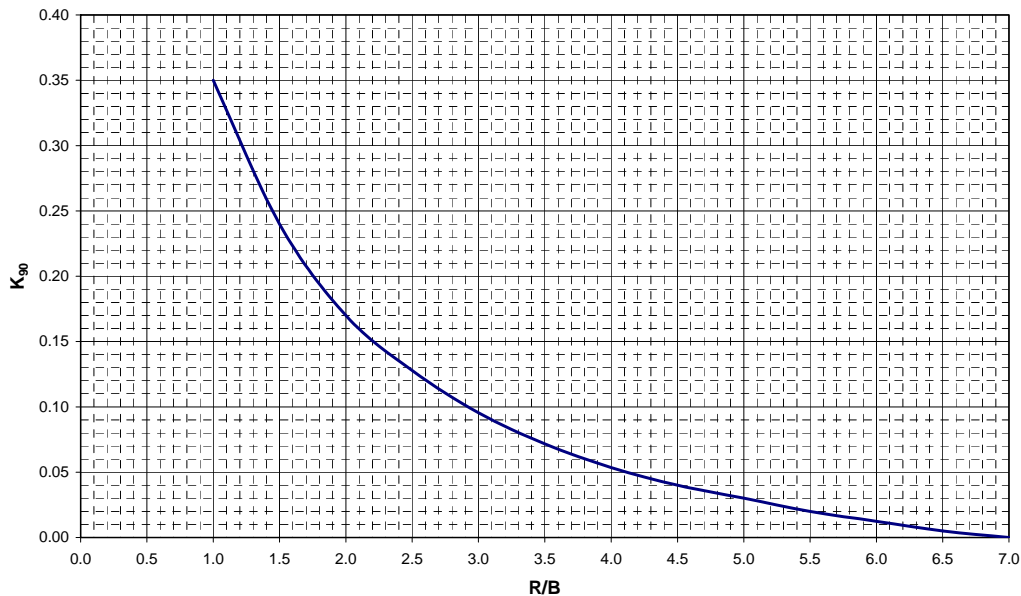
Recommended Procedure: It is recommended that bend losses be omitted in the model setup. If, after careful calibration, it is found that the modeled profiles tend to depart from observed profiles based on historical high water marks, examine the channel to determine if bends in the channel might have a significant impact on headloss. A bend loss is considered significant if the ratio of the radius of curvature (R) to the average channel width (B) is less than seven. For $(R/B) > 7$, bend losses are essentially zero and it is unlikely that a bend will occur whose ratio is less than one. Therefore, this method applies to $1 \leq (R/B) \leq 7$. If the bend satisfies this range, it is recommended that bend losses be added to the friction losses in reaches where significant bends are present. This is done by adjusting the Manning's "n" value using the "Vertical Variation in n Values" option in the cross section editor. To determine the adjusted "n" values, several steps should be followed:

1. Determine the bend angle, θ



2. Determine the bend loss coefficient for a 90-degree bend angle, K_{90}

Figure 1: 90-Degree Bend Loss Coefficients
(After: Holley, 1991)



3. Determine the bend loss coefficient for the angle in question, K_b

$$K_b = K_{90} \left(\frac{K_b}{K_{90}} \right)$$

Where,

θ	K_b/K_{90}
15°	0.0
30°	0.1
45°	0.2
60°	0.4
75°	0.8
90°	1.0
135°	1.2
180°	1.3

4. Determine the adjusted Manning's "n" value, n_{adj}

$$n_{adj} = \left(n^2 + \frac{2.22 R_h^{4/3} K_b}{2gL} \right)^{1/2}$$

Where,

- n = original Manning's "n" value
- R_h = hydraulic radius (feet), assumed unchanged from pre-adjusted value
- K_b = bend loss coefficient
- g = acceleration due to gravity (32.2 ft/sec²)
- L = length along bend to next downstream cross section (feet)

5. Based on several calibration profiles, define the adjusted "n" value for various stages. It is noted that based on the equations above, for a given channel, the deeper the flow, the higher the adjusted "n" value and the smaller the headloss. This would appear to be consistent with what is expected (e.g., less headloss is expected when the channel is flowing out-of-banks than when contained entirely within the channel).

Assumptions: Additional losses can be adequately represented by adjusting Manning's "n" value. This assumption is supported in a report (dated October 30, 1991) entitled, "Head Losses in Open for Flood Calculations," prepared for the Harris County Flood Control District by Dr. E.R. Holley of the University of Texas Center for Research in Water Resources.

Testing Procedure: In a June 26, 1991 letter from Klotz/Associates to the Harris County Flood Control District various methods were discussed for incorporating bend losses into the White Oak Bayou HEC-2 models. Among other methods discussed in this letter were the method described above and a method using the X5 record to set changes in the water surface elevation based on calculated bend losses. The letter recommended the use of the "X5" method and, ultimately, the effective HEC-2 model for White Oak Bayou (based on a February 1995 Letter of Map Revision request by Klotz/Associates, Inc.) incorporated bend losses using this method. Thus, the bend loss was directly input by adding a cross section one foot upstream of the upstream cross section in a bend. Therefore, the bend loss was added at the upstream end of the bend reach and was not distributed throughout the bend.

Minor testing was done using HEC-RAS to determine the effects of the “X5” method and the “n” value adjustment method. One advantage of the HEC-RAS option for vertical variation in “n” values (over the similar HEC-2 option) is the ability to adjust “n” values vertically and horizontally at the same time. Therefore, traditional problems associated with the NV record in HEC-2 (i.e., a single “n” value for both channel and overbanks) are avoided in HEC-RAS. It is not possible to vary the channel “n” value vertically while maintaining overbank “n” values which are consistent with observed field data. Thus, it is possible to apply bend losses to the channel only.

Test Results: It was determined that using a modified “n” value would be desirable when compared to setting a change in water surface elevations or energy grade. This was mainly for ease of input and smooth transition between cross sections around a bend.

Final Notes: Bend losses were added to the White Oak Bayou HEC-2 model after calibration in the early 1990s revealed difficulty in matching observed water surface profiles during historical events. The same difficulty did not appear to exist in the Brays Bayou watershed which has a similar (not the same, but similar) cross section configuration as White Oak. When comparing the two channels, it was apparent to HCFCD staff that White Oak was significantly more sinuous, prompting the thought that losses due to major bends in the channel could be the cause of the problems with profile matching.

In the June 26, 1991 letter to HCFCD from Klotz/Associates, six possibilities were identified to account for bend losses in HEC-2. The various methods and an explanation of each are given below.

- *J2 Record, Field 6*—multiplies the NC, NV, or NH values by a given percent change for the entire HEC-2 analysis. This would spread out the losses over the entire HEC-2 model.
- *NH Record*—use weighted “n” values. This approach would possibly require several different “frequency” related HEC-2 models.
- *NV Record*—use NV records to specify stage related “n” values allowing bend losses to vary with water surface elevation. This would require a complete re-evaluation of all current NC and NH values (presumably because of the problem identified above under “Testing Procedure”).
- *X1 Record*—exaggerate the channel reach length to account for the additional loss. This would impact profile plotting routines and could cause other difficulties.
- *X2 Record, Field 6 (BLOSS)*—add a fixed loss at specific locations. This would require different “frequency” related HEC-2 models.
- *X5 Record*—add a fixed loss at a specific location. This would allow a single model which could utilize different bend losses for different frequency events.

For the reasons described above, the two most logical options were the NV record (which allowed the losses to vary with stage) and the X5 record (which allowed the losses to vary with frequency). In conversations with Klotz/Associates and HCFCD staff, it was noted that the X5 method was settled on because the NV method created too much loss for lower frequency profiles (e.g., 100-year) and too little loss for higher frequency events (e.g., 2-year). As stated previously, to incorporate the X5 losses, an additional cross section was added one foot upstream of the last cross section in a bend (i.e., the cumulative loss in a bend was added at a single cross section). This allowed for the model to account for both friction and bend losses separately.

Both the X5 method and the NV method are available in HEC-RAS. The X5 method is available under the "Options/Set Changes in WS and EG" menu in the Steady Flow Data Editor. The NV method is available in the Cross Section Editor under "Options/Vertical Variation in n Values."

One additional item should be noted and that is that in the 211(f) project for White Oak Bayou performed by Carter & Burgess, Inc., the bend losses were omitted. For that study, a statistical analysis was performed to attempt to quantify the impacts of the bend losses. That statistical analysis led the study team to conclude that the impacts

were insignificant for their work and resulted in the bend loss omission for the White Oak Bayou 211(f) study. It is expected that the bend loss problem would affect only a few channels, if any—White Oak and perhaps some of the larger natural channels such as Spring Creek and possibly Cedar Bayou and Cypress Creek.

Committee Resolution: