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► **To cite this version:**

B. Camenen, M. Larson. On the accuracy of equivalent roughness height formulas in practical applications. *Journal of Hydraulic Engineering*, 2013, 139 (3), p. 331 - p. 335. 10.1061/(ASCE)HY.1943-7900.0000670 . hal-00920719

**HAL Id: hal-00920719**

**<https://hal.science/hal-00920719>**

Submitted on 19 Dec 2013

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# On the accuracy of equivalent roughness height formulas in practical applications

Benoît Camenen<sup>\*†</sup> and Magnus Larson<sup>‡</sup>

## 1 **Abstract**

2 This paper presents a discussion on the application and accuracy of rough-  
3 ness height formulas from a practical point of view. Such formulas have been  
4 proposed to describe the equivalent roughness height for plane bed condi-  
5 tions based on the Shields parameter. The application of these relationships  
6 requires an iterative solution technique. However, as this note demonstrates,  
7 the roughness estimates are not always reliable since the application of the  
8 formulas yield large discrepancies in the results.

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<sup>\*</sup>Corresponding author, [benoit.camenen@irstea.fr](mailto:benoit.camenen@irstea.fr)

<sup>†</sup>Irstea, UR HHLY, Hydrology-Hydraulics Research Unit, 3 bis quai Chauveau, CP  
220, F-69336 Lyon cedex 09, France

<sup>‡</sup>Dept. of Water Resources Eng., Lund University, Box 118, S-221 00 Lund, Sweden,  
E-mail: [magnus.larson@tvrl.lth.se](mailto:magnus.larson@tvrl.lth.se)

## 9 **Keywords**

10 Roughness height, friction factor, plane bed, sheet flow, experimental data,  
11 predictive formula, iterative formula.

## 12 **Introduction**

13 Estimating bedload transport is of great importance for engineering design  
14 and morphodynamic modelling; yet bedload transport rate predictions are  
15 based on insufficient understanding of the resistance to flow in alluvial chan-  
16 nels. Although the roughness height or resistance coefficient are quite dif-  
17 ficult to estimate, they remain fundamental parameters in bed shear stress  
18 and sediment transport calculations. Total resistance to the flow in a river  
19 includes grain resistance, bedform resistance, resistance due to lateral and  
20 vertical channel irregularities, as well as dissipation due to the solid trans-  
21 port (Recking et al., 2008). Meyer-Peter and Müller (1948) introduced a lin-  
22 ear decomposition of the total resistance coefficient, which may be rewritten  
23 as a linear decomposition of the total bed roughness (Soulsby, 1997; Came-  
24 nen et al., 2006).

25 Excluding form drag, the value of the equivalent roughness height  $k_s$  still  
26 varies considerably depending on the configuration of the grains forming the  
27 bed roughness or the dissipation due to sediment transport. If  $k_s$  is generally  
28 assumed to be proportional to a characteristic bed grain size (Bathurst,

29 1985), several authors showed a significant increase in  $k_s$  when bedload  
30 transport occurs, even for coarse sediments (Campbell et al., 2005; Recking  
31 et al., 2008). This increase in roughness is often explained for fine sediments  
32 by the dissipation of energy in the sheet flow layer that appears for large  
33 Shields parameter values (dimensionless bed shear stress defined such as  
34  $\theta = RI/[(s - 1)d_{50}]$ , with  $R$ : hydraulic radius,  $I$ : energy slope,  $s$ : relative  
35 density of the sediment to the fluid, and  $d$ : grain size). Sediments move  
36 collectively along the bottom mainly in a layer and  $k_s \approx \delta_s$ , where  $\delta_s$  is the  
37 thickness of the sheet flow layer (Wilson, 1989). This movement induces an  
38 effective roughness ratio  $k_s/d$ , where  $d$  is the grain size diameter, up to 50  
39 (Wilson, 1966; Nnadi and Wilson, 1992; Sumer et al., 1996). Based on a  
40 large data set, Recking et al. (2008) found a significant difference in the fit  
41 of a logarithmic law for the friction coefficient depending on the presence of  
42 sediment movement, which can be described in terms of a roughness, such  
43 as the  $k_s/d$ -ratio, that varies from approximately 1 for a fixed bed to 3 for  
44 a moderate sediment transport rate.

45 Generally, this phenomenon was expressed using a Shields parameter  
46 value  $\theta$  over a critical value for the upper plane bed regime, where  $k_s$  is not  
47 only a function of the median grain size  $d_{50}$  but also of  $\theta$  (Wilson, 1966; Nnadi  
48 and Wilson, 1992; Yalin, 1992; van Rijn, 1993; Sumer et al., 1996; Bayram  
49 et al., 2003; Camenen et al., 2006) or of bedload transport rate, if the latter  
50 is assumed to be directly related to the Shields parameter (Meyer-Peter

51 and Müller, 1948). Most of the formulas were validated for fine sediments  
52 and high shear stresses. Sumer et al. (1996) observed that the roughness  
53 height may be a function of a dimensionless settling velocity  $\varpi_s = W_s/u_*$   
54 (where  $W_s$  is the settling velocity and  $u_*$  the shear velocity). Camenen  
55 et al. (2006) also showed that large values on the effective roughness ratio  
56  $k_s/d_{50}$  can be observed for lower values of the Shields parameter. They  
57 proposed a new relationship for the critical Shields parameter for the upper  
58 plane regime, which is a function of a dimensionless settling velocity  $W_{s*} =$   
59  $[(s - 1)^2/(g\nu)]^{1/3}W_s$  (where  $g$  the acceleration due to gravity, and  $\nu$  the  
60 kinematic viscosity of the fluid) and a Froude number  $Fr = U_c/\sqrt{gh}$  (where  
61  $U_c$  the steady current velocity and  $h$  the water depth). Then, for a low  
62 Froude number and coarse sediment, large effective roughness ratios are  
63 also observed. The flow seems to be affected by the bed load transport for  
64 these particular cases as much as in the sheet flow transport cases.

65       However, one important aspect of these previous studies is that all the  
66 equations presented in Camenen et al. (2006) have been fitted knowing the  
67 total shear stress, since it is directly computed from energy slope measure-  
68 ments. Therefore, in practical applications, as the total Shields parameter  
69 is an unknown, these relationships induce an iterative method for the com-  
70 putation of the roughness height and the total Shields parameter. Two  
71 main problems may occur: (1) a solution does not always exist depending  
72 on the proposed equation (or more than one solution exist), and (2) the

73 iterative approach in itself induces a large discrepancy in the results. The  
74 main objective of the present study is to highlight these problems induced by  
75 the iterative method. Although similar problems occur for oscillatory flows  
76 (Camenen et al., 2009), this paper is dealing with unidirectional flows only.  
77 As a consequence, this paper corresponds to an extension to Camenen et al.  
78 (2006) dealing with the application of the previously proposed formulas.

## 79 **Iterative calculation of the roughness height**

80 Since experimental data implicate a relationship where roughness height is  
81 a function of the total shear stress, an iterative calculation is needed to  
82 compute the roughness. Indeed, from a practical point of view, the Shields  
83 parameter  $\theta$  is an unknown.

### 84 **Iterative procedure**

The iterative solution can be expressed using the relationship for the friction coefficient (see Eq. 12 in Camenen et al., 2006) and the definition of the Shields parameter (see Eq. 2 in Camenen et al., 2006). Assuming the hydraulic radius  $R$ , median grain size  $d_{50}$ , relative density of sediments  $s$ , and depth averaged velocity  $U_c$  as input parameters, the only unknown parameter to estimate the Shields parameter is the roughness height  $k_s$  or roughness length  $z_0 = k_s/30$ . Thus, the Shields parameter can be expressed

as a function of  $k_s/d_{50}$ :

$$\theta = F\left(\frac{k_s}{d_{50}}\right) = \left[\frac{\kappa}{(R+z_0)/R \ln((R+z_0)/z_0) - 1}\right]^2 \frac{U_c^2}{(s-1)gd_{50}} \quad (1)$$

Employing the relationships proposed by different authors (Wilson, 1966; Yalin, 1992; van Rijn, 1993; Sumer et al., 1996; Bayram et al., 2003; Camenen et al., 2006), which can be expressed as  $k_s/d_{50} = f(\theta)$ , equation 1 can easily be solved using an iterative technique. The function  $f$  may often be written according to:

$$\frac{k_s}{d_{50}} = f(\theta) = a_1 + a_2\theta^b \quad (2)$$

85 where  $a_1$ ,  $a_2$  and  $b$  are constants ( $0 \leq a_1 \leq 5$ ,  $1 \leq b \leq 2.5$  and  $a_2$  varies  
86 with  $b$  and authors;  $b$  can also be a function of the settling velocity, shear  
87 velocity or/and the Froude number).

88 The iterative procedure may be summarized as follows:

- 89 - fix a first value for  $k_s$ :  $k_{s,p1} = \alpha d_{50}$  ( $\alpha = 2$  may be used assuming skin  
90 roughness),
- 91 - compute  $\theta_p$  using Eq. 1 with  $k_s = k_{s,p1}$ ,
- 92 - compute a new value for  $k_s$ :  $k_{s,p2}$  using Eq. 2 with  $\theta = \theta_p$ ,
- 93 - while  $|1 - k_{s,p1}/k_{s,p2}| > \epsilon$ , fix  $k_{s,p1} = k_{s,p2}$  and iterate the previous two  
94 operations

95 Of course, the choice of  $\alpha$  and  $\epsilon$  ( $\epsilon = 0.01$  was used) may slightly influence  
96 the results.

97 **Graphical interpretation of the iterative procedure**

98 It is also possible to graphically represent this iterative procedure. Fig.  
99 1 presents curves of the effective roughness ratio plotted against the total  
100 Shields parameter obtained from various equations  $k_s/d_{50} = f(\theta)$  and the  
101 equation  $k_s/d_{50} = F^{-1}(\theta)$  (represents calculation of  $k_s/d_{50}$  from the total  
102 Shields parameter, see Eq. 1) for two particular cases: figure (a) corresponds  
103 to an experimental case from Smart (1984); figure (b) corresponds to an  
104 experimental case from Nnadi and Wilson (1992).

105 *Fig. 1 here*

106 In Fig. 1, it can be seen that both functions  $f(\theta)$  and  $F^{-1}(\theta)$  are in-  
107 creasing functions of  $\theta$ , but  $f(\theta)$  is a convex function, whereas  $F^{-1}(\theta)$  is a  
108 concave function. In general, this means that either two solutions coexist  
109 (*cf.* Fig. 1(a)) or no solution exists (*cf.* Fig. 1(b) for the Sumer *et al.* for-  
110 mula). Another observation is that the similar slopes of these curves ( $f(\theta)$   
111 and  $F^{-1}(\theta)$ ) close to the intersection points induces large uncertainties (*cf.*  
112 Fig. 1(a) for the formula proposed by Camenen *et al.* or (b) for all formu-  
113 las). This effect is not as strong for the Wilson formula since the power on  
114  $\theta$  is not as large as for the other equations (1 compared to 1.5 or 2.5). The  
115 iterative method will never induce a better result compared to the fitted  
116 curve because the two curves  $f$  and  $F^{-1}$  are increasing functions of  $\theta$ . In  
117 Fig. 2 are two different situations presented that illustrates this point:



- 118 1. A slight underestimation is observed using the fitted curve. The ex-  
119 perimental point is  $E_1$  with the coordinates  $(\theta_1, (k_s/d_{50})_{1e})$ . The esti-  
120 mated value of  $(k_s/d_{50})$  from the fitted curve is such that  $(k_s/d_{50})_{1p} <$   
121  $(k_s/d_{50})_{1e}$  (point  $P_1$ ). From the iterative method (point  $I_1$ ), the pre-  
122 dicted value of  $\theta$  is necessarily smaller ( $\theta_{1i} < \theta_1$ ). Thus,  $(k_s/d_{50})_{1i} <$   
123  $(k_s/d_{50})_{1p} < (k_s/d_{50})_{1e}$ .
- 124 2. A slight overestimation is observed using the fitted curve. The ex-  
125 perimental point is  $E_2$  with the coordinates  $(\theta_2, (k_s/d_{50})_{2e})$ . The esti-  
126 mated value of  $(k_s/d_{50})$  from the fitted curve is such that  $(k_s/d_{50})_{2p} >$   
127  $(k_s/d_{50})_{2e}$  (point  $P_2$ ). From the iterative method, the predicted value  
128 of  $\theta$  is necessarily larger ( $\theta_{2i} > \theta_2$ ). Thus,  $(k_s/d_{50})_{2i} > (k_s/d_{50})_{2p} >$   
129  $(k_s/d_{50})_{2e}$ .

130 *Fig. 2 here*

131 In conclusion, it appears that the iterative method is not very accurate  
132 from a practical point of view. A solution does not always exist, and most  
133 of the time, two solutions coexist. If there is an error between the data and  
134 the fitted curve, it will necessarily be larger after employing the iterative  
135 method.

136 **Results obtained from the iterative methods**

137 **Prediction of the roughness height**

In order to discuss the iterative method, several empirical formulas for Eq. 2 presented in Camenen et al. (2006) were tested using the same data set for plane bed conditions also introduced in Camenen et al. (2006). In Table 1 are the predictions of equivalent roughness height within a factor of 2 ( $P2$  in %) and 5 ( $P5$  in %) of the measured values presented for the different formulas, as well as the mean value ( $mr$ ) and standard deviation ( $sr$ ) of the ratio  $r = k_{s,pred}/k_{s,expe}$ . The term “ $Er_{log}$ ” (logarithmic error index, in %) is defined as,

$$Er_{log} = \frac{100}{n} \sum_1^n \left| \log \left[ \frac{(k_s/d_{50})_{pred}}{(k_s/d_{50})_{expe}} \right] \right| \quad (3)$$

138 in which  $n$  denotes the number of observations. When no solution existed,  
139 a value  $k_s/d_{50} = 250$  (maximum roughness height ratio observed exper-  
140 imentally) was chosen, and when several solutions coexisted, the small-  
141 est value was chosen. As a comparison, results using the grain related  
142 roughness ( $k_s = 2d_{50}$ ) and a recently published formula by Rickenmann  
143 and Recking (2011) are also presented ( $U_c/u_* = 4.416(R/d_{84})^{1.904}\{1 +$   
144  $[R/(1.283d_{84})]^{1.618}\}^{-1.083}$ ).

145 *Tab. 1 here*

146 Although good agreement is found towards the data using the exper-  
147 imental total shear stress values, the iterative solution for a pair ( $k_s, \theta$ )

148 induces large discrepancies in the results. As a matter of fact, the accuracy  
149 of the results ( $P2$ ) drops with 10% to 30% depending on the formula used  
150 (*cf.* table 1 and Fig. 3). A large increase in  $Er_{log}$  and  $sr$  is also observed  
151 for all the formulas. It clearly appears that the discrepancy of the itera-  
152 tive methods depends mainly on the value of the coefficient  $b$  proposed in  
153 each formula ( $b = 1.0$  for the Wilson formula,  $b = 2.5$  for the Sumer *et al.*  
154 formula and  $b = 1.7$  for the Bayram *et al.* and Camenen *et al.* formulas).  
155 Indeed, the larger the coefficient  $b$  is, the closer are the two slopes of the  
156 functions  $F^{-1}(\theta)$  and  $f(\theta)$ , and the larger the uncertainties induced by the  
157 iterative solution. As a result, the obtained  $k_s/d_{50}$  values often correspond  
158 to the minimum value imposed by the formula (skin roughness). This ob-  
159 servation is clearly confirmed by the graphs in Fig. 3. It also explains the  
160 relatively better results observed for the Sumer *et al.* formula since there is  
161 a higher minimum value ( $k_s/d_{50} = 4.5$ ) when  $\varpi = W_s/u_* \leq 0.9$  ( $u_* = \sqrt{\tau/\rho}$   
162 is the shear velocity, where  $\tau$  is the bottom shear stress and  $\rho$  the density  
163 of the fluid). In Fig. 3, it appears that the Sumer *et al.* and Bayram *et*  
164 *al.* formulas yield unrealistic results corresponding to their minimum value  
165 (2 or 4.5 for the Sumer *et al.* formula depending on  $\varpi$ ) for most of the  
166 cases. If the Camenen *et al.* formula yields the best result using the mea-  
167 sured Shields parameter, the obtained result from the iterative solution is  
168 quite poor and it yields large uncertainties. As many of the experimental  
169 cases correspond to a roughness height close to the skin roughness height

170 ( $k_s \approx 2d_{50}$ ), to use the skin roughness height yields nearly as good result as  
171 the more complex formulas. The Rickenmann and Recking formula yields  
172 slightly better results but very similar as for the skin roughness. No formula  
173 gives good predictions for the roughness height when  $k_s > 10d_{50}$ , but the  
174 Wilson formula yields much better results than the other formulas. Finally,  
175 the Wilson formula (with a minimum value  $k_s/d_{50}$ ) produces the best results  
176 among the studied formulas, although the scatter is significant.

177 *Fig. 3 here*

### 178 **Prediction of the total Shields parameter**

179 A comparison between the predicted and the observed value of the Shields  
180 parameter shows similar results. A quite large discrepancy is observed for  
181 the prediction of the total Shields parameter whatever formula used. Even  
182 the Wilson formula, which seems to yield slightly better results for the es-  
183 timation of the roughness height, does not produce any improvement for  
184 the estimation of the total Shields parameter. The Wilson, Bayram *et al.*,  
185 and Camenen *et al.* formulas yield overestimations with relatively large dis-  
186 persion in the predictions. The Sumer *et al.* formula, since it gives values  
187 for  $k_s/d_{50}$  between 2 and 5, presents slightly better results compared to the  
188 other formulas. Finally, it appears that using the skin Shields parameter  
189 (or the Rickenmann and Recking formula) yields predictions, which are as  
190 good as using the other studied formulas, apart for the large values on the

191 Shields parameter, which are underestimated.

192 *Tab. 2 here*

## 193 **Conclusions**

194 Many formulas have been proposed to estimate the roughness height in the  
195 case of plane beds. All the previous authors proposed equations assuming  
196 that the total Shields parameter is already known. Although these formulas  
197 present interesting results for the understanding of the physics, and reveal  
198 the main factors governing roughness, they are not applicable from an engi-  
199 neering point the view. The iterative formulas resulting from these equations  
200 yields very large scatter in the results. Finally, the use of the skin Shields  
201 parameter produces nearly as good results, apart for large values of the total  
202 Shields parameter, which are underestimated. There is thus a strong need  
203 for a new method to correctly predict the total Shields parameter for the  
204 upper regime where the roughness height is no more a function of the grain  
205 size only ( $k_s/d_{50} > 5$ ).

## 206 **Acknowledgments**

207 This work was in part conducted under the Inlet Modeling System Work  
208 Unit of the Coastal Inlets Research Program, U.S. Army Corps of Engineers,  
209 and in part (B.C.) under the sponsorship of the Japanese Society for the

210 Promotion of Sciences.

## 211 **Notation**

212 The following symbols and subscripts are used in this paper:

$a_1, a_2, b$  : constants depending on authors for the function  $f$ ,

$d, d_{50}, d_{84}$  : sand diameter, median sand diameter and diameter for which 84% of  
sediment by weight is smaller, respectively,

$Er_{log}$  : logarithm error index (in %),

$f$  : empirical functions used to estimate  $k_s/d_{50}$ ,

$F$  : function of  $k_s/d_{50}$  used to calculate the Shields parameter,

$Fr$  : Froude number,

$g$  : acceleration due to gravity ( $g = 9.81$  m/s),

213

$h$  : water depth,

$I$  : energy slope,

$k_s$  : roughness height,

$mr, sr$  : mean value and standart deviation ,

$P_{1.2}, P_2, P_5$  : predictions within a factor of 1.2, 2 and 5, respectively (in %) of the  
measured values,

$R$  : hydraulic radius,

$s$  : relative density of the sediment to the fluid ( $s = 2.65$  for silica in water),

- $u_*$  : friction velocity,
- $U_c$  : depth-averaged velocity,
- $W_s$  : settling velocity,
- $W_{s*}$  : nondimensional settling velocity ( $W_{s*} = (s - 1)^{2/3} / (g\nu)^{1/3} W_s$ ).
- $z_0$  : roughness length ( $z_0 = k_s/30$ ),
- 214  $\alpha$  : constant used for the first estimation of  $k_s$  in the iterative procedure,
- $\kappa$  : von Karman constant ( $\kappa = 0.41$ ),
- $\nu$  : kinematic water viscosity ( $\nu = 10^{-6} \text{ m}^2/\text{s}$ ),
- $\theta$  : total Shields parameter due to steady current,
- $\varpi_s$  : suspension parameter ( $\varpi_s = W_s/u_*$ ).

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Table 1: Prediction of the equivalent roughness height within a factor of 2 and 5 of the measured values together with a logarithmic error index, and the mean value and standard deviation of the ratio  $r = k_{s,pred}/k_{s,expe}$  for the studied formulas (R. & R.: Rickenmann & Recking) and all data, and data where  $(k_s/d_{50})_{expe} > 10$  (influence of the iterative method on the results).

	all data									
	experimental value of $\theta$					iterative method				
<b>Author(s)</b>	<i>P2</i>	<i>P5</i>	<i>Er<sub>log</sub></i>	<i>mr</i>	<i>sr</i>	<i>P2</i>	<i>P5</i>	<i>Er<sub>log</sub></i>	<i>mr</i>	<i>sr</i>
$k_s = 2d_{50}$	41	73	49	-0.3	0.57			–		
R. & R.	41	81	44	-0.03	0.55			–		
Wilson	57	90	33	0.01	0.45	44	76	50	0.08	0.67
Sumer <i>et al.</i>	54	87	34	-0.09	0.50	45	79	46	-0.09	0.62
Bayram <i>et al.</i>	57	88	34	-0.02	0.47	39	74	53	0.09	0.72
Camenen <i>et al.</i>	74	97	23	-0.01	0.30	36	66	61	-0.01	0.81
	data where $(k_s/d_{50})_{expe} > 10$									
	experimental value of $\theta$					iterative method				
<b>Author(s)</b>	<i>P2</i>	<i>P5</i>	<i>Er<sub>log</sub></i>	<i>mr</i>	<i>sr</i>	<i>P2</i>	<i>P5</i>	<i>Er<sub>log</sub></i>	<i>mr</i>	<i>sr</i>
$k_s = 2d_{50}$	0	0	120	-1.2	0.23			–		
R. & R.	0	2	80	-0.8	0.25			–		
Wilson	52	70	47	-0.4	0.55	33	53	69	-0.5	0.71
Sumer <i>et al.</i>	29	60	64	-0.6	0.57	4	36	85	-0.8	0.57
Bayram <i>et al.</i>	46	67	52	-0.5	0.54	9	31	91	-0.4	0.54
Camenen <i>et al.</i>	68	96	27	-0.2	0.29	11	30	93	-0.6	0.83

Table 2: Prediction of total Shields parameter within a factor of 1.2 and 2 of the measured values together with a logarithmic error index, and the mean value and standard deviation of the ratio  $r = \theta_{pred}/\theta_{expe}$  for the studied formulas (and the skin Shields parameter, as well as the Rickenmann & Recking formula) and all data.

<b>Author(s)</b>	<i>P1.2</i>	<i>P2</i>	<i>Er<sub>log</sub></i>	<i>mr</i>	<i>sr</i>
skin Shields parameter	30	75	22	-0.14	0.28
Rickenmann & Recking	28	80	20	-0.04	0.27
Wilson	31	75	31	0.08	0.68
Sumer <i>et al.</i>	32	78	27	-0.01	0.59
Bayram <i>et al.</i>	30	73	38	0.14	0.77
Camenen <i>et al.</i>	27	67	41	0.07	0.83

(a) (b)

Fig. 1a Fig. 1b

Figure 1: Graphical illustration of the iterative method for two specific cases (experimental data from Smart (a) and Nnadi & Wilson (b)).

Figure 2: Graphical illustration of the iterative method for the two main situations.

experimental value of  $\theta$     iterative method

(a)	Fig. 3a1	Fig. 3a2
(b)	Fig. 3b1	Fig. 3b2
(c)	Fig. 3c1	Fig. 3c2

Figure 3: Effect on the results using an iterative method for the Wilson (a) (with a minimum value of  $k_s/d_{50} = 2$ ), Sumer *et al.* (b), and Camenen *et al.* (c) formulas.

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Fig. 1a  
[Click here to download Figure: testks3.png](#)

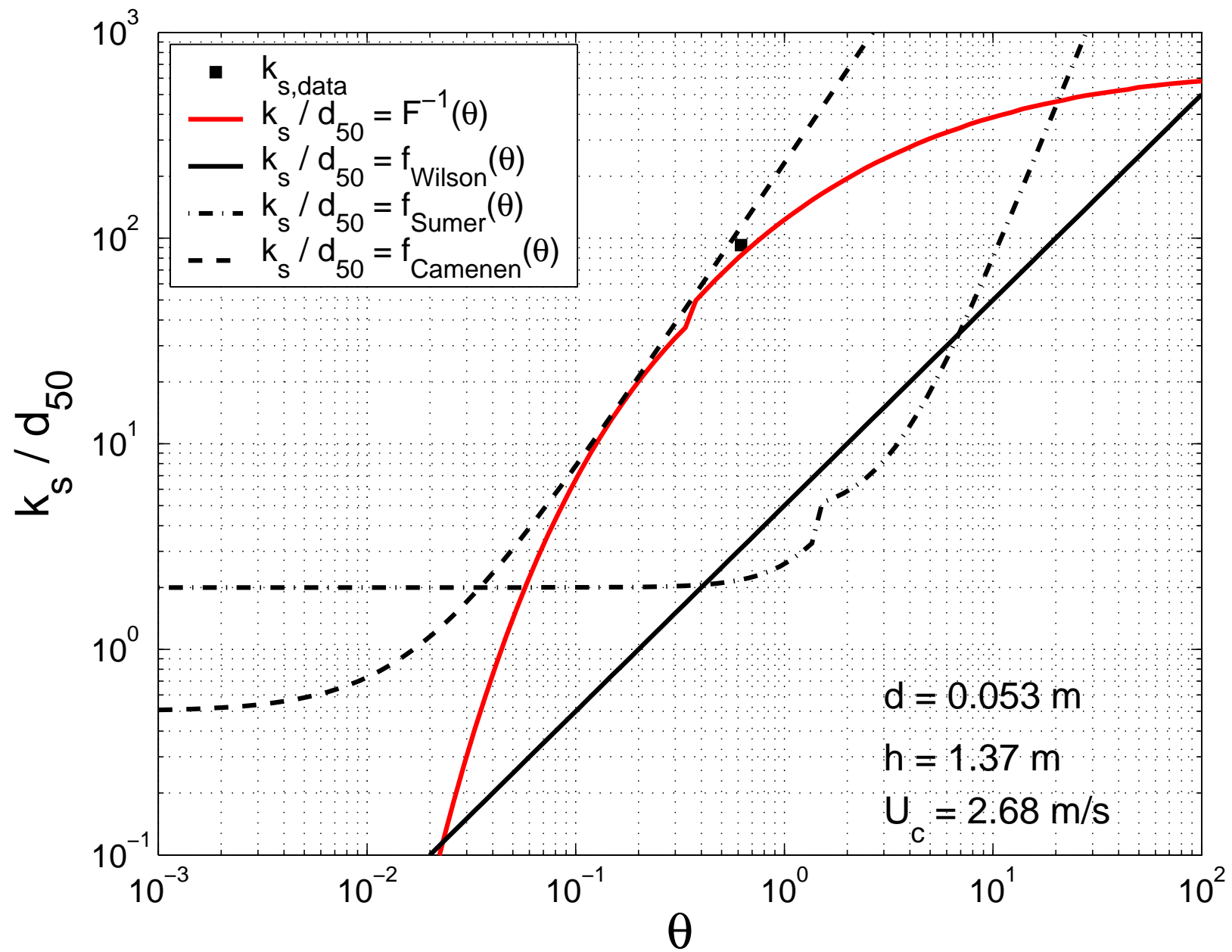
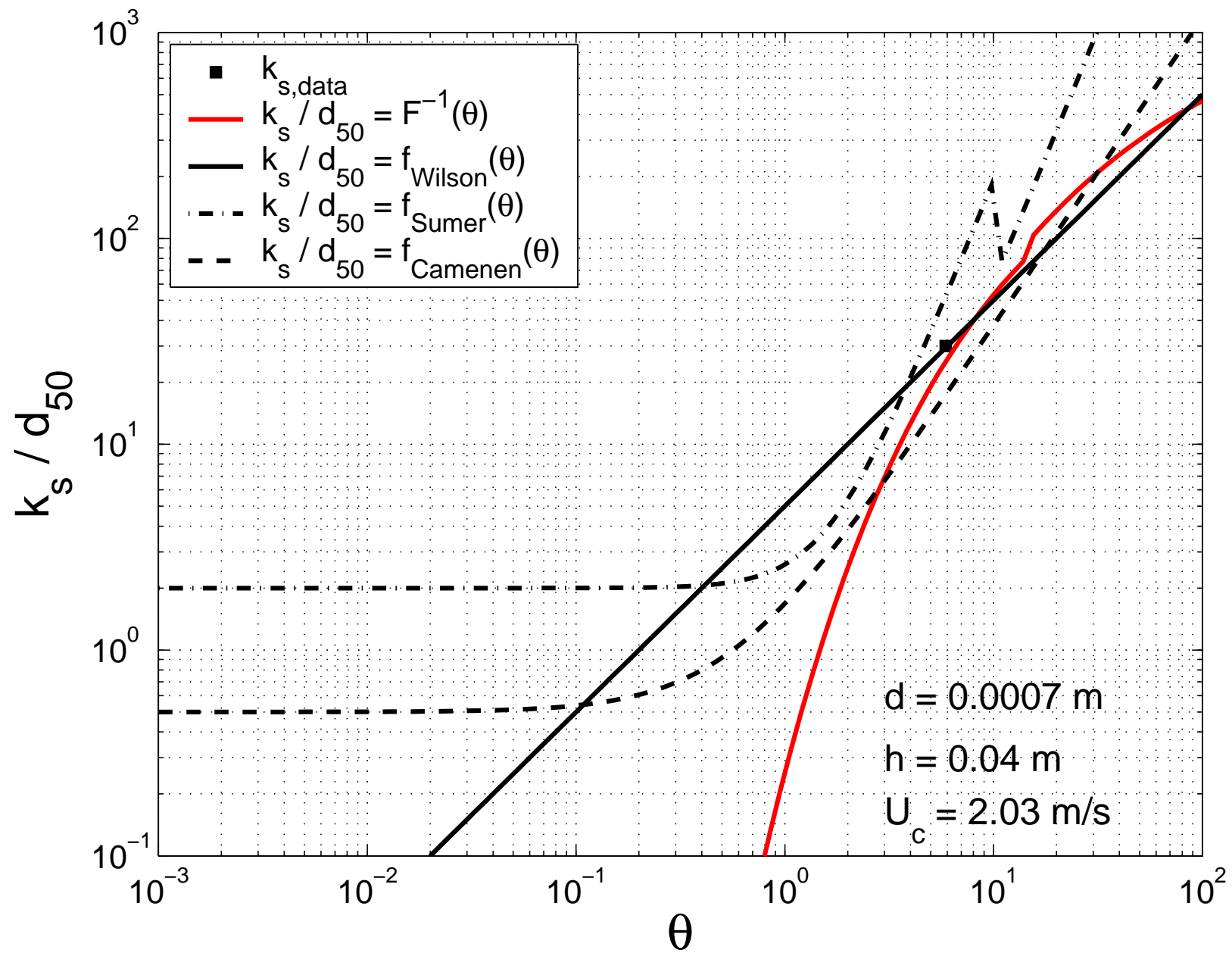
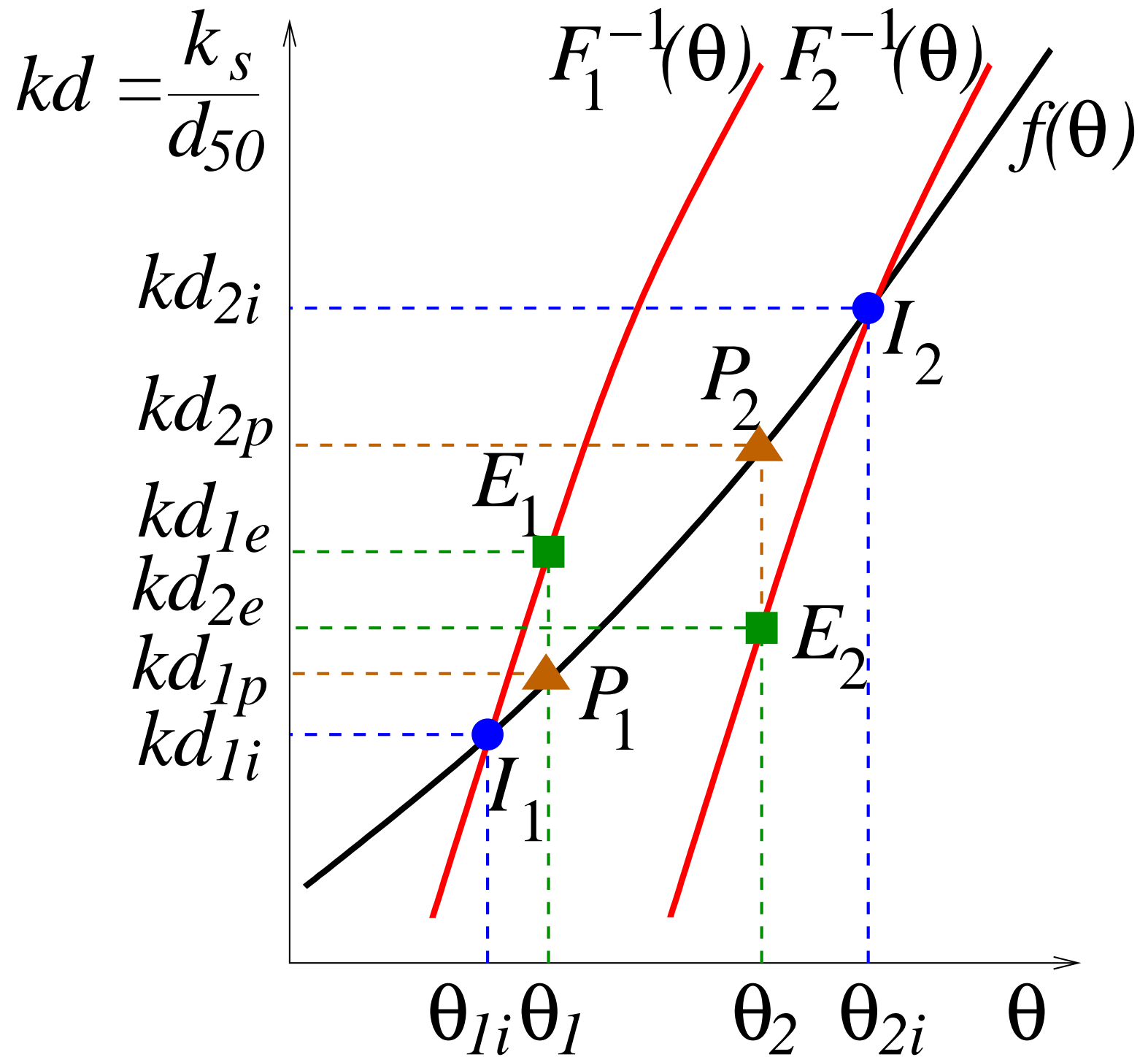


Fig. 1b







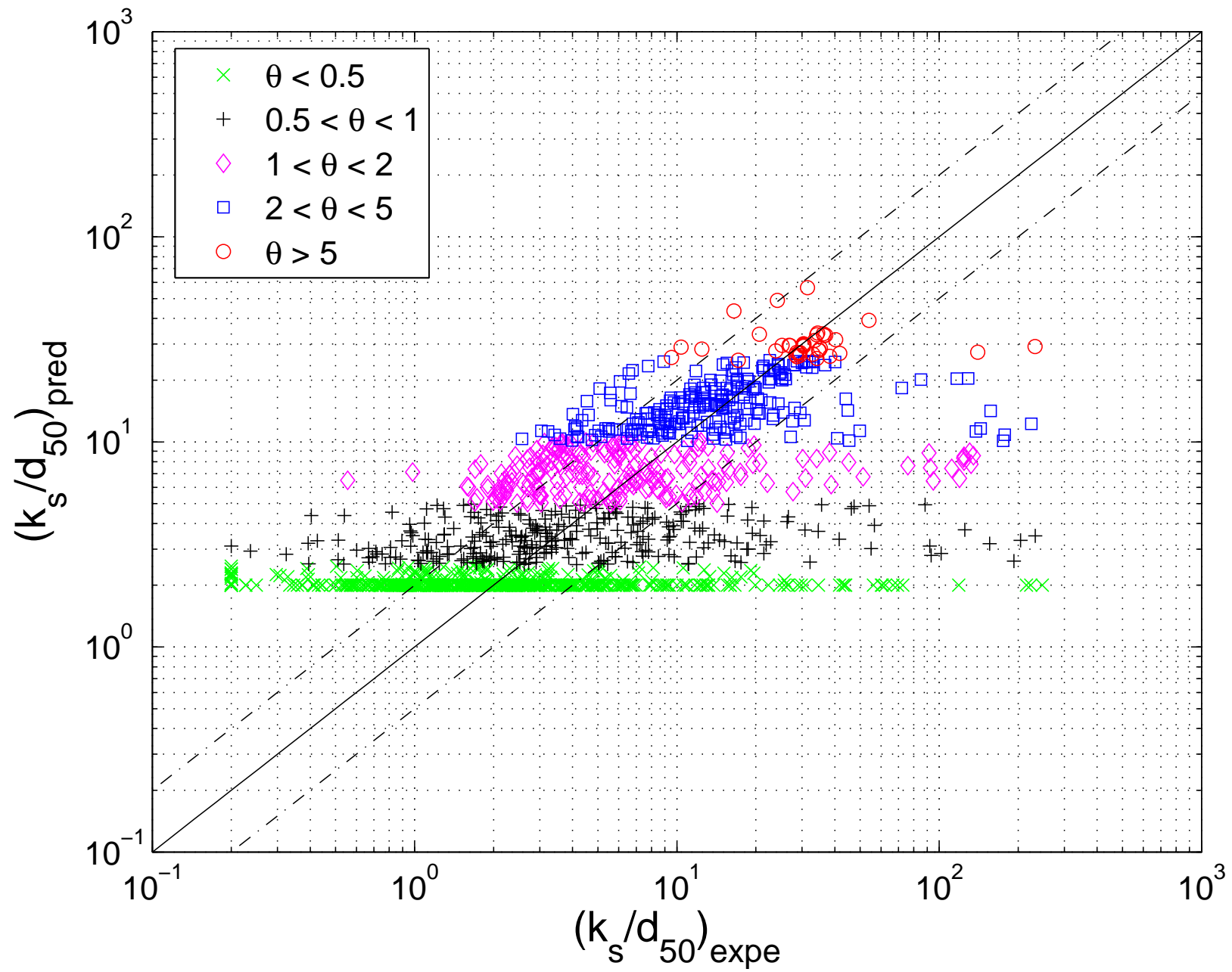


Fig. 3a2

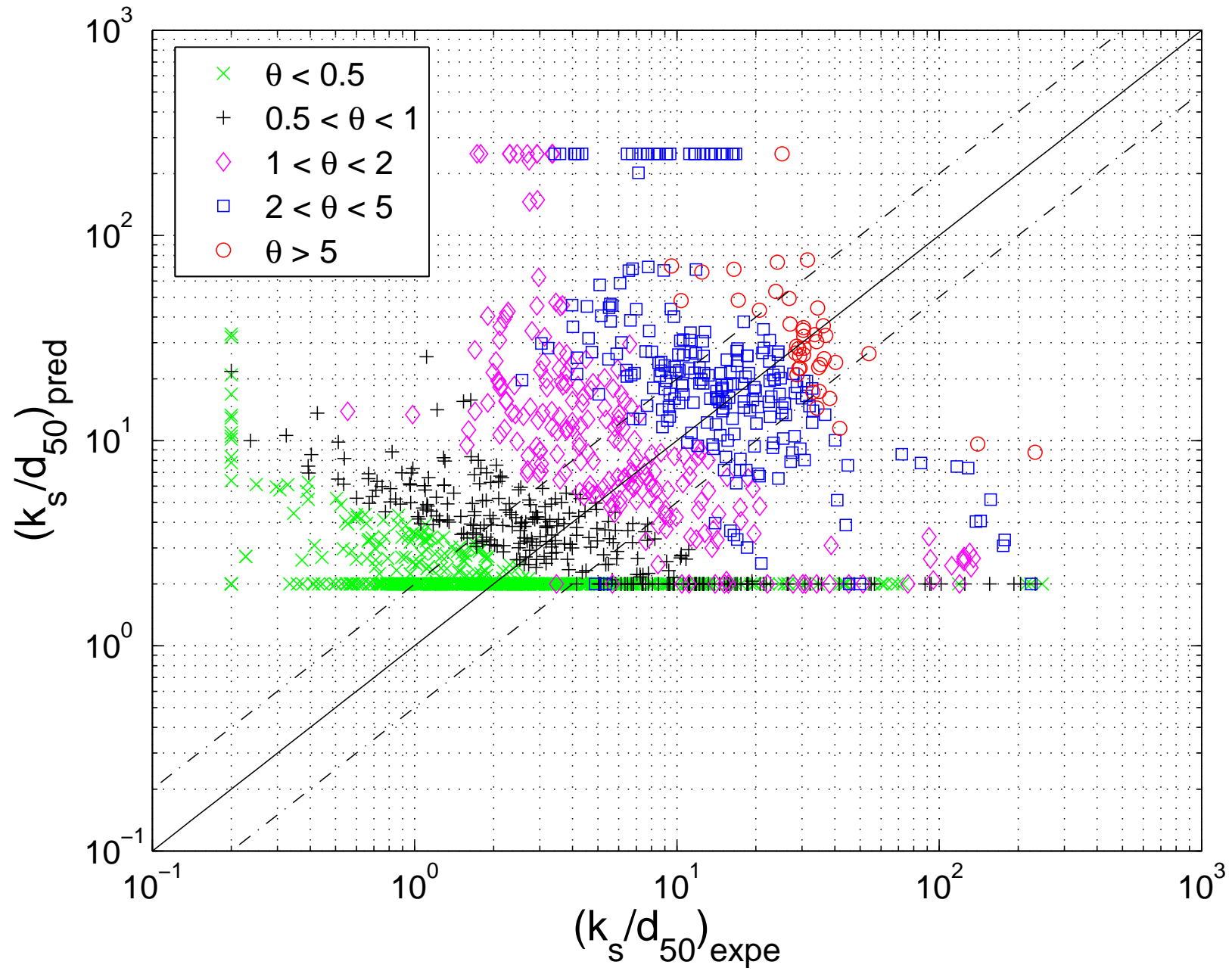
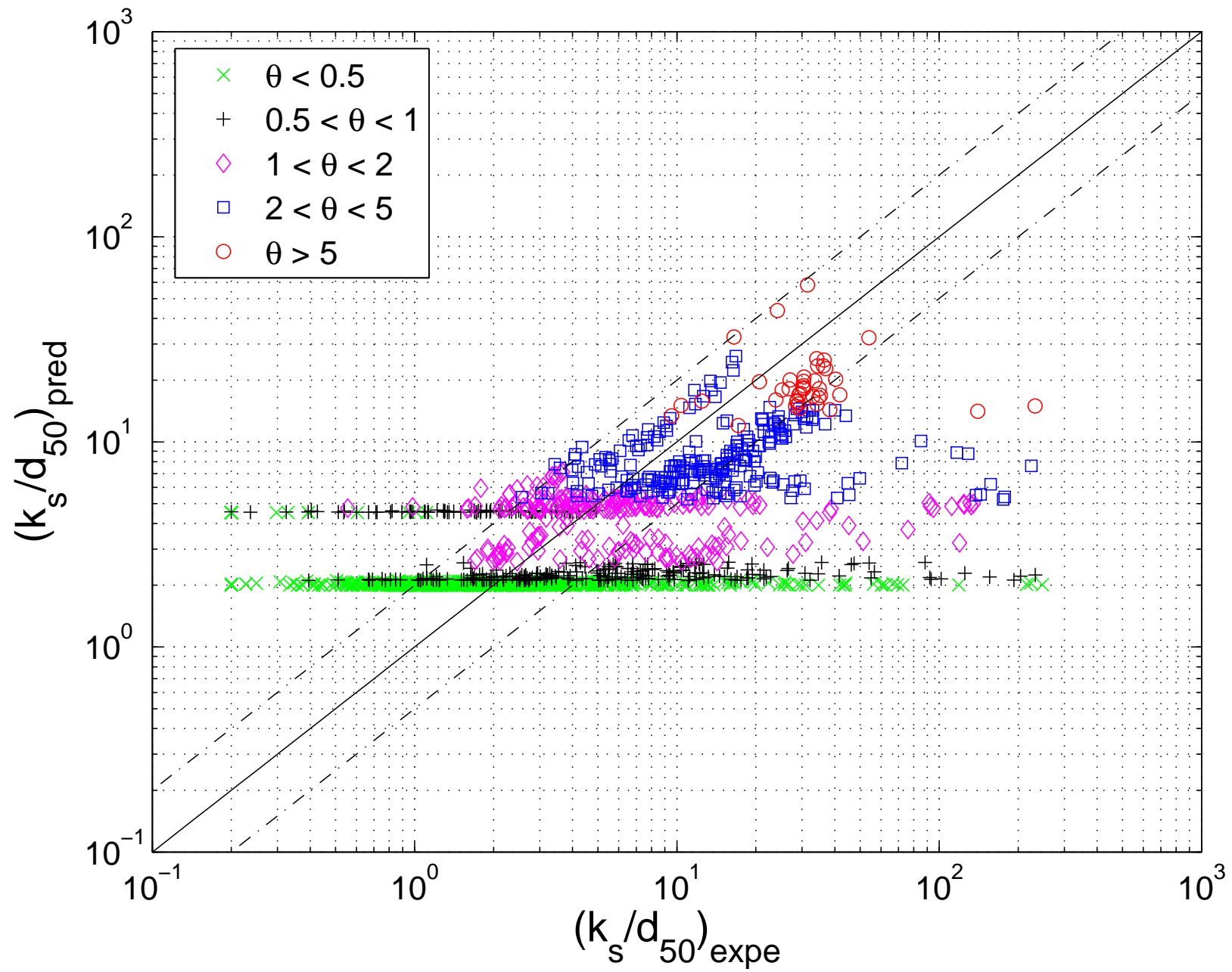
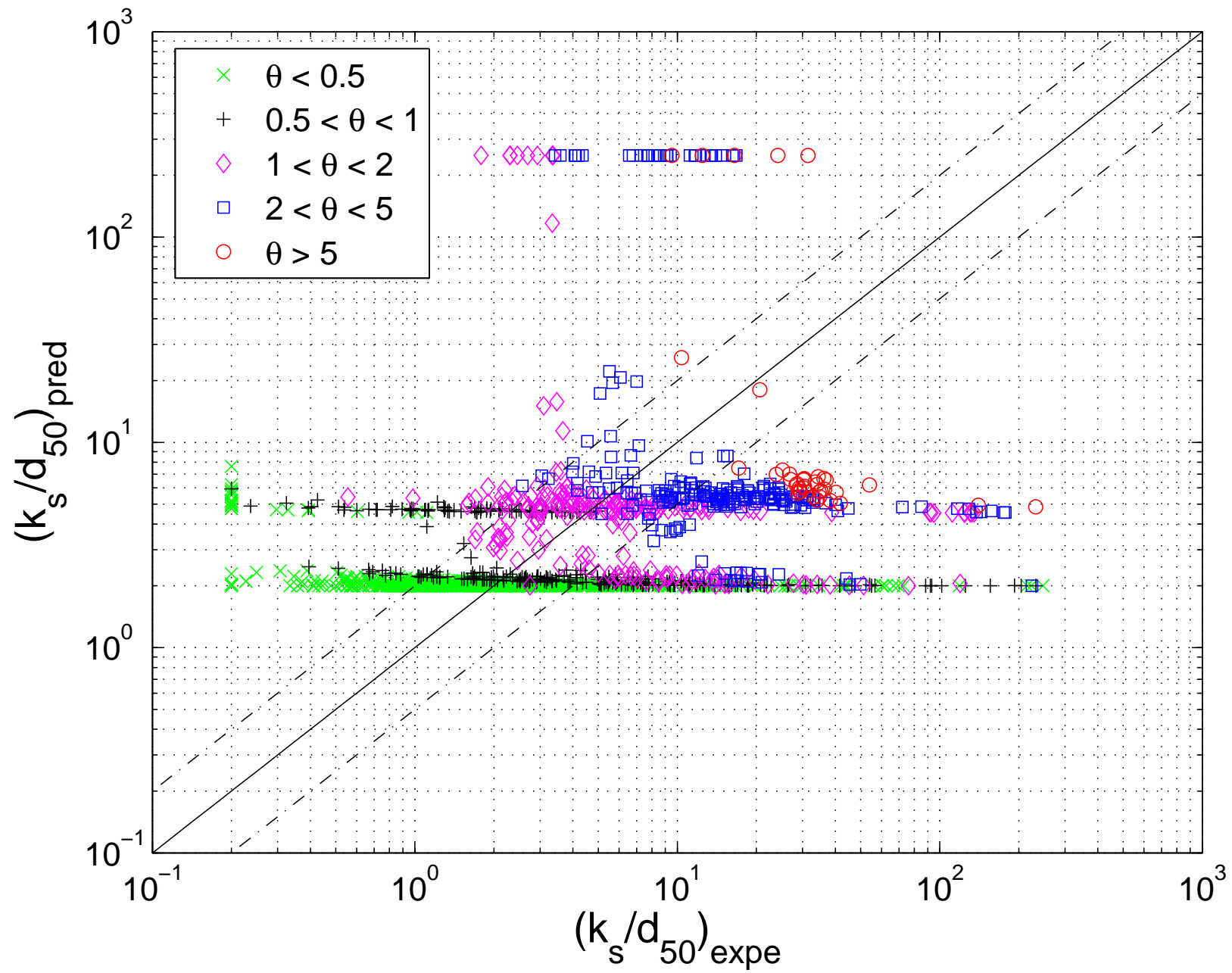
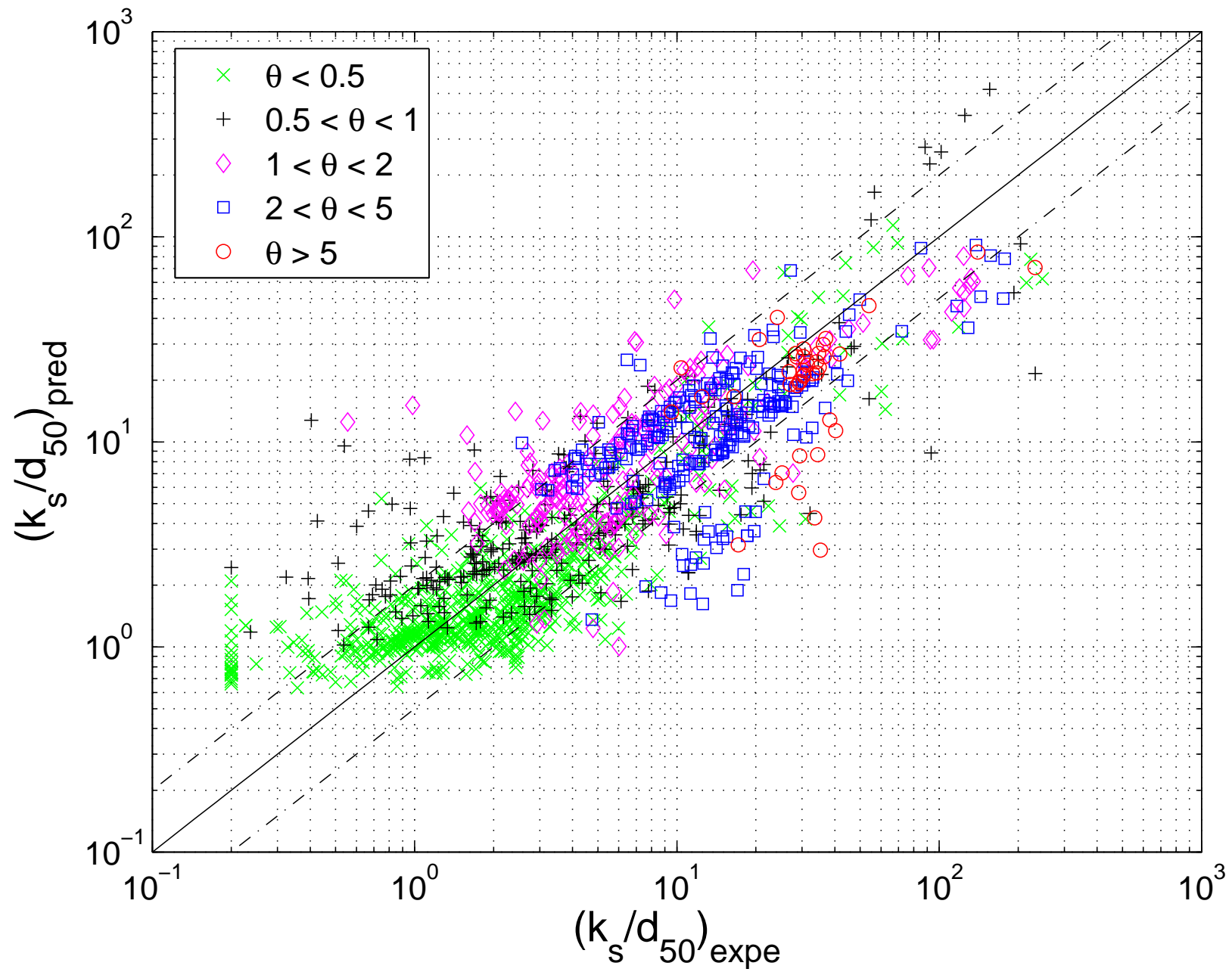
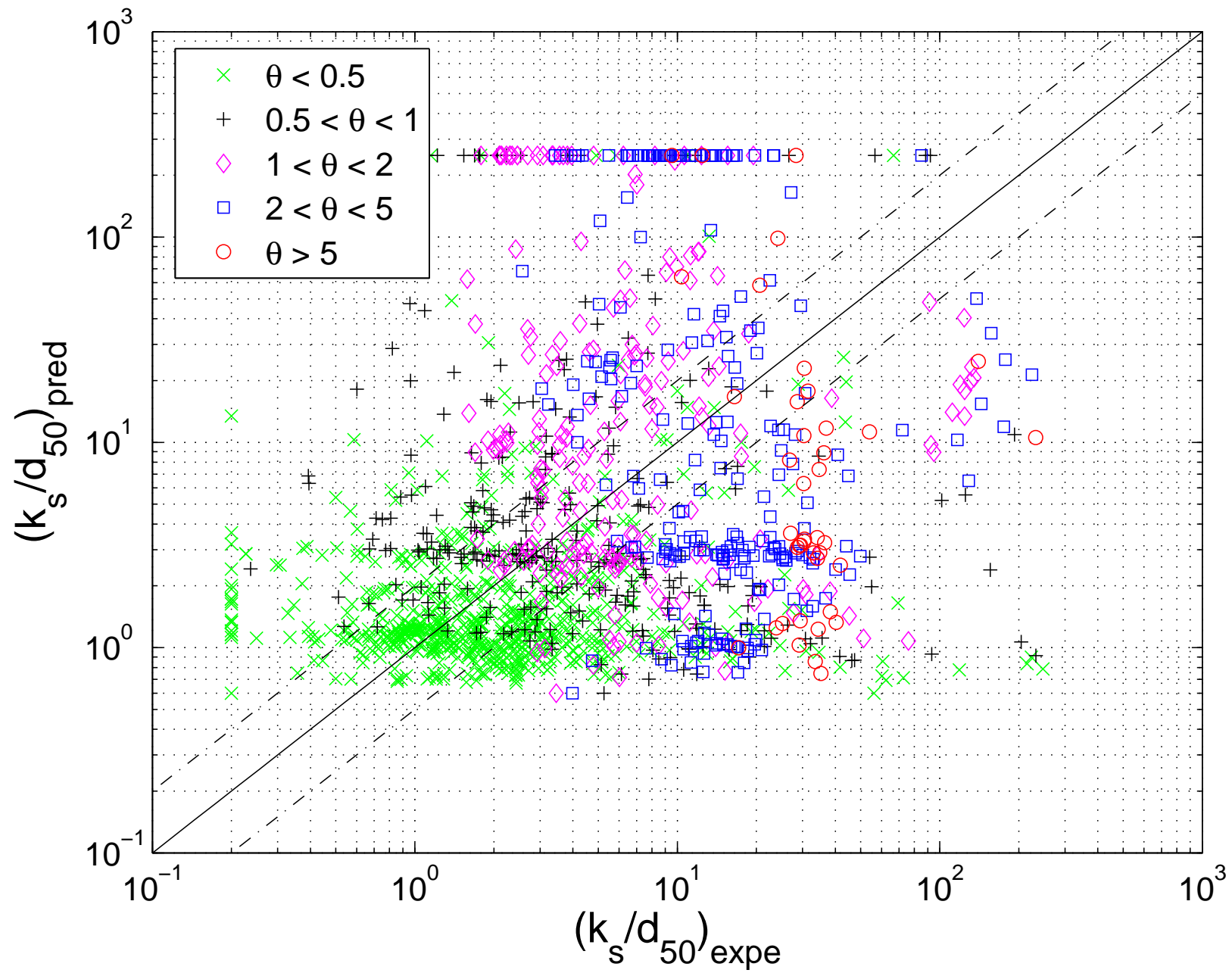


Fig. 3b1











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Manuscript Number: HYENG 7789

Type: Technical Note

Publication Title: On the accuracy of equivalent roughness height formulas in practical applications

Manuscript Authors: B. CAMENEN, M. LARSSON

Corresponding Author, Name and Address: Benoit CAMENEN, HILLY, Iskra  
3 bis rue Chauveau, CP220 F-69336 Lyon Cedex 09

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<b>Count # of text lines per page</b>	18
# of words per page	210.00
<b>Count # of pages (don't add references &amp; abstract)</b>	11
Title & Abstract	500
<b>Total # refs</b>	0
Length of Text is	2810
	249
	3059
	3

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1-column table = up to 60 characters wide	2-column table = 61 to 120 characters wide
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1-column table = up to 60 characters wide by:	2-column table = 61 to 120 characters wide by:
17 lines (or less) = 158 word equiv.	17 lines (or less) = 315 word equiv.
up to 34 lines = 315 word equiv.	up to 34 lines = 630 word equiv.
up to 51 lines = 473 word equiv.	up to 51 lines = 945 word equiv.
up to 68 text lines = 630 word equiv.	up to 68 text lines = 1260 word equiv.

**C. Total Characters wide by Total Text lines = word equiv.** as shown in the table above. **Add word equivalents** for each table in the column labeled "Word Equivalents."

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**Figure type size can't be smaller than 6 point (2mm).**

**B. Use ruler** and measure figure to fit 1 or 2 column wide format.

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**C. Then use** a ruler to check the height of each figure (including title & caption).

1-column fig. = up to 3.5 in.(88.9mm) wide by:	2-column fig. = 3.5 to 7 in.(88.9 to 177.8 mm) wide by:
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up to 5 in.(127mm) high = 315 word equiv.	up to 5 in.(127mm) high = 630 word equiv.
up to 7 in.(177.8mm) high = 473 word equiv.	up to 7 in.(177.8mm) high = 945 word equiv.
up to 9 in.(228.6mm) high = 630 word equiv.	up to 9 in.(228.6mm) high = 1260 word equiv.

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Tables	Word Equivalents	Figures
Table 1	317	Figure 1
2	158	2
3	0	3
4	0	4
5	0	5
6	0	6
7	0	7
8	0	8
9	0	9
10	0	10
11	0	11
12	0	12
13	0	13
14	0	14
15	0	15
Please double-up tables/figures if additional space is needed (ex. 20+21).		16
		17
		18
		19
		20 and 21

Total Tables/Figures:	1421
Total Words of Text:	3059

(word equivalents)

<b>Total words and word equivalents:</b>	<b>4480</b>
<b>printed pages:</b>	<b>4</b>



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<b>Figures:</b>
Word Equivalents
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Ref.: Ms. No. HYENG-7789

"On the application of the equivalent roughness height formulas" by Benoît Camenen  
& Magnus Larson

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