**Chapter 1**

Problems **1-1** through **1-6** are for student research. No standard solutions are provided.

**1-7** From Fig. 1-2, cost of grinding to ± 0.0005 in is 270%. Cost of turning to ± 0.003 in is 60%.

Relative cost of grinding vs. turning = 270/60 = 4.5 times *Ans.*

­­­­­­­­­­­­­­­­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-8** *CA* = *CB*,

 10 + 0.8 *P* = 60 + 0.8 *P* − 0.005 *P* 2

 *P* 2 = 50/0.005 ⇒ *P* = 100 parts *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-9** Max. load = 1.10 *P*

 Min. area = (0.95)2*A*

 Min. strength = 0.85 *S*

 To offset the absolute uncertainties, the design factor, from Eq. (1-1) should be

 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 **1-10** (**a**) *X*1 + *X*2:

 ****

(**b**) *X*1 − *X*2:

 

 (**c**) *X*1 *X*2:

 

 (**d**) *X*1/*X*2:

 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 **1-11** (**a**) *x*1 =  = 2.645 751 311 1

 *X*1 = 2.64 (3 correct digits)

 *x*2 =  = 2.828 427 124 7

 *X*2 = 2.82 (3 correct digits)

 *x*1 + *x*2 = 5.474 178 435 8

 *e*1 = *x*1 −  *X*1 = 0.005 751 311 1

 *e*2 = *x*2 −  *X*2 = 0.008 427 124 7

 *e* = *e*1 + *e*2 = 0.014 178 435 8

 Sum = *x*1 + *x*2 = *X*1 + *X*2 + *e*

 = 2.64 + 2.82 + 0.014 178 435 8 = 5.474 178 435 8 Checks

 (**b**) *X*1 = 2.65, *X*2 = 2.83 (3 digit significant numbers)

 *e*1 = *x*1 −  *X*1 = − 0.004 248 688 9

 *e*2 = *x*2 −  *X*2 = − 0.001 572 875 3

 *e* = *e*1 + *e*2 = − 0.005 821 564 2

 Sum = *x*1 + *x*2 = *X*1 + *X*2 + *e*

 = 2.65 +2.83 − 0.001 572 875 3 = 5.474 178 435 8 Checks

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-12** 

 Table A-17: *d* = in *Ans.*

 Factor of safety: 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-13** (**a**)

|  |  |  |  |
| --- | --- | --- | --- |
| *x* |  *f*  | *f x* | *f x*2 |
| 60 | 2 | 120 | 7200 |
| 70 | 1 | 70 | 4900 |
| 80 | 3 | 240 | 19200 |
| 90 | 5 | 450 | 40500 |
| 100 | 8 | 800 | 80000 |
| 110 | 12 | 1320 | 145200 |
| 120 | 6 | 720 | 86400 |
| 130 | 10 | 1300 | 169000 |
| 140 | 8 | 1120 | 156800 |
| 150 | 5 | 750 | 112500 |
| 160 | 2 | 320 | 51200 |
| 170 | 3 | 510 | 86700 |
| 180 | 2 | 360 | 64800 |
| 190 | 1 | 190 | 36100 |
| 200 | 0 | 0 | 0 |
| 210 | 1 | 210 | 44100 |
|  | 69 | 8480 | 1 104 600 |

 Eq**.** (1-6) 

 Eq. (1-7) 

 (**b**) Eq. (1-5) 

 Interpolating from Table (A-10)

 0.2600 0.3974

 0.2607 *x*  *x* = 0.3971

 0.2700 0.3936

 *N*Φ(−0.2607) = 69 (0.3971) = 27.4 ≈ 27 *Ans.*

 From the data, the number of instances less than 115 kcycles is

 2 + 1 + 3 + 5 + 8 + 12 = 31 (the data is not perfectly normal)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-14**

|  |  |  |  |
| --- | --- | --- | --- |
| *x* |  *f* |  *f x* |  *f x*2 |
| 174 | 6 | 1044 | 181656 |
| 182 | 9 | 1638 | 298116 |
| 190 | 44 | 8360 | 1588400 |
| 198 | 67 | 13266 | 2626668 |
| 206 | 53 | 10918 | 2249108 |
| 214 | 12 | 2568 | 549552 |
| 222 | 6 | 1332 | 295704 |
|  | 197 | 39126 | 7789204 |

 Eq**.** (1-6) 

 Eq. (1-7) 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-15** 

 Eq. (1-5) 

 Thus, *x*10 = 122.9 + 30.3 *z*10 = *L*10

 From Table A-10, for 10 percent failure, *z*10 = −1.282. Thus,

 *L*10 = 122.9 + 30.3(−1.282) = 84.1 kcycles *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-16**

|  |  |  |  |
| --- | --- | --- | --- |
| *x* | *f* | *fx* | *fx*2 |
| 93 | 19 | 1767 | 164331 |
| 95 | 25 | 2375 | 225625 |
| 97 | 38 | 3686 | 357542 |
| 99 | 17 | 1683 | 166617 |
| 101 | 12 | 1212 | 122412 |
| 103 | 10 | 1030 | 106090 |
| 105 | 5 | 525 | 55125 |
| 107 | 4 | 428 | 45796 |
| 109 | 4 | 436 | 47524 |
| 111 | 2 | 222 | 24642 |
|  | 136 | 13364 | 1315704 |

 Eq. (1-6) 

 Eq. (1-7) 

**Note**, for accuracy in the calculation given above,needs to be of more significant figures than the rounded value.

 For a normal distribution, from Eq. (1-5), and a yield strength exceeded by 99 percent

 (*R* = 0.99, *pf* = 0.01),

 
Solving for the yield strength gives

 *x*0.01 = 98.26 + 4.30 *z*0.01

 From Table A-10, *z*0.01 = − 2.326. Thus

 *x*0.01 = 98.26 + 4.30(− 2.326) = 88.3 kpsi *Ans*.

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**1-17** Eq. (1-9): *R* == 0.98(0.96)0.94 = 0.88

 Overall reliability = 88 percent *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-18** Obtain the coefficients of variance for strength and stress

 ****

 ****

 For *R* = 0.99, from Table A-10, *z* = − 2.326.

 Eq. (1-12):

 

 From the given equation for stress,

 

 Solving for *d* gives

 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-19** Obtain the coefficients of variance for stress and strength

 ****

 ****

 (**a**) 

 Eq. (1-11): 

 Interpolating Table A-10,

 1.61 0.0537

 1.6127 Φ  Φ = 0.0534

 1.62 0.0526

 *R* = 1 − 0.0534 = 0.9466 *Ans*.

 

 (**b**) 

 

 3.6 0.000159

 3.605 Φ  Φ = 0.00015645

 3.7 0.000108

 *R* = 1 − 0.00015645 = 0.9998 *Ans*.

 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-20** 

 From footnote 9 of text,

 

 ****

 ****

 ****

 Eq. (1-11): 

 From Table A-10, Φ(− 1.635) = 0.05105

 *R* = 1 − 0.05105 = 0.94895 = 94.9 percent *Ans*.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-21** *a* = 1.500 ± 0.001 in

 *b* = 2.000 ± 0.003 in

 *c* = 3.000 ± 0.004 in

 *d* = 6.520 ± 0.010 in

 (**a**) = 6.520 − 1.5 − 2 − 3 = 0.020 in

 = 0.001 + 0.003 + 0.004 +0.010 = 0.018

 *w* = 0.020 ± 0.018 in *Ans.*

 (**b**) From part (a), *w*min = 0.002 in. Thus, must add 0.008 in to . Therefore,

 = 6.520 + 0.008 = 6.528 in *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-22** *V = xyz*, and *x = a* ± Δ *a*, *y = b* ± Δ *b*, *z = c* ± Δ *c*,

 

 

 The higher order terms in Δ are negligible. Thus,

 

 and, 

 For the numerical values given, 

 

 *V* = 8.4375 ± 0.0360 in3 *Ans.*

 This answer yields  in, whereas, exact is in

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-23**

 *w*max = 0.05 in, *w*min = 0.004 in



 Thus, Δ *w* = 0.05 − 0.027 = 0.023 in, and then, *w* = 0.027 ± 0.023 in.

 

 *tw* =  ⇒ 0.023 = *ta* + 0.002 + 0.005 ⇒ *ta* = 0.016 in

 Thus, *a* = 1.569 ± 0.016 in *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-24** 

 

 *Do* = 4.012 ± 0.036 in *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-25** From O-Rings, Inc. (oringsusa.com), *Di* = 9.19 ± 0.13 mm, *d* = 2.62 ± 0.08 mm

 

 

 *Do* = 14.43 ± 0.29 mm *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-26** From O-Rings, Inc. (oringsusa.com), *Di* = 34.52 ± 0.30 mm, *d* = 3.53 ± 0.10 mm

 

 

 *Do* = 41.58 ± 0.50 mm *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-27** From O-Rings, Inc. (oringsusa.com), *Di* = 5.237 ± 0.035 in, *d* = 0.103 ± 0.003 in

 

 

 *Do* = 5.443 ± 0.041 in *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-28** From O-Rings, Inc. (oringsusa.com), *Di* = 1.100 ± 0.012 in, *d* = 0.210 ± 0.005 in

 

 

 *Do* = 1.520 ± 0.022 in *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-29** From Table A-2,

 (**a**) *σ* = 150/6.89 = 21.8 kpsi *Ans.*

 (**b**) *F* = 2 /4.45 = 0.449 kip = 449 lbf *Ans.*

 (**c**) *M* = 150/0.113 = 1330 lbf ⋅ in = 1.33 kip ⋅ in *Ans.*

 (**d**) *A* = 1500/ 25.42 = 2.33 in2 *Ans.*

 (**e**) *I* = 750/2.544 = 18.0 in4 *Ans.*

 (**f**) *E* = 145/6.89 = 21.0 Mpsi *Ans.*

 (**g**) *v* = 75/1.61 = 46.6 mi/h *Ans.*

 (**h**) *V* = 1000/946 = 1.06 qt *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-30** From Table A-2,

(**a**) *l* = 5(0.305) = 1.53 m *Ans.*

 (**b**) *σ* = 90(6.89) = 620 MPa *Ans.*

 (**c**) *p* = 25(6.89) = 172 kPa *Ans.*

 (**d**) *Z* =12(16.4) = 197 cm3 *Ans.*

 (**e**) *w* = 0.208(175) = 36.4 N/m *Ans.*

 (**f**) *δ* = 0.001 89(25.4) = 0.048 0 mm *Ans.*

 (**g**) *v* = 1 200(0.0051) = 6.12 m/s *Ans.*

 (**h**)  = 0.002 15(1) = 0.002 15 mm/mm *Ans.*

 (**i**) *V* = 1830(25.43) = 30.0 (106) mm3 *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-31**

 (**a**) *σ* = *M /Z* = 1770/0.934 = 1895 psi = 1.90 kpsi *Ans.*

 (**b**) *σ* = *F /A* = 9440/23.8 = 397 psi *Ans.*

 (**c**) *y =Fl*3*/*3*EI* = 270(31.5)3/[3(30)106(0.154)] = 0.609 in *Ans.*

 (**d**) *θ = Tl /GJ* = 9 740(9.85)/[11.3(106)(*π* /32)1.004] = 8.648(10−2) rad = 4.95° *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-32**

 (**a**) *σ =F /* *wt* = 1000/[25(5)] = 8 MPa *Ans.*

 (**b**) *I = bh*3 /12 = 10(25)3/12 = 13.0(103) mm4 *Ans.*

 (**c**) *I =π d*4/64 = *π* (25.4)4/64 = 20.4(103) mm4 *Ans.*

 (**d**) *τ =*16*T /π d* 3 = 16(25)103/[*π* (12.7)3] = 62.2 MPa *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-33**

 (**a**) *τ =F /A* = 2 700/[*π* (0.750)2/4] = 6110 psi = 6.11 kpsi *Ans.*

 (**b**) *σ =* 32*Fa/π d* 3 = 32(180)31.5/[*π* (1.25)3] = 29 570 psi = 29.6 kpsi *Ans.*

 (**c**) *Z =π* (*do*4 − *di*4)/(32 *do*) = *π* (1.504 − 1.004)/[32(1.50)] = 0.266 in3 *Ans.*

 (**d**) *k* = (*d* 4*G*)/(8*D* 3 *N*) = 0.062 54(11.3)106/[8(0.760)3 32] = 1.53 lbf/in *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_