2.2.3 Choosing the Crack Geometry

The next few pages provide a "catalog" of currently available crack cases in NASGRO, organized by crack category. The summary Table 2.2.1 provides a listing of all crack cases for each crack type, followed by groups of figures in Fig. 2.2.4 through Fig. 2.2.73 that provide schematic diagrams of each SIF model and supplementary information about nomenclature, loading, and geometry limits. These diagrams are taken directly from the NASFLA GUI. The GUI allows the user to export the diagrams as bitmap files that can be integrated into user reports. The following is a grouped list of the figures according to crack type:

- **Through crack (TC)** geometries are shown in Fig. 2.2.4 through Fig. 2.2.34
- **Corner crack (CC)** geometries are shown in Fig. 2.2.35 through Fig. 2.2.48
- **Surface-crack (SC)** geometries are shown in Fig. 2.2.49 through Fig. 2.2.68
- **Embedded crack (EC)** geometries are shown in Fig. 2.2.69
- **Hybrid crack (HC)** geometries are shown in Fig. 2.2.70
- **Standard specimen (SS)** geometries are shown in Fig. 2.2.71 through Fig. 2.2.72
- **Boundary element (BE)** crack cases are shown in Fig. 2.2.73

Besides the crack geometries listed above, four data table (DT) cases, four SIF table (KT) cases, and one polynomial solution (PS01) are also available for use.

The user selects the desired crack geometry by clicking on the **Show crack case library** button in the **Geometry** tab of the GUI and then using selection boxes in the pop-up window. After selecting the appropriate crack case, the figure is displayed in the **Geometry** tab and the user can enter dimensional information such as width, thickness, diameter, etc. in the text boxes provided.

The majority of the crack cases come with standard loading types such as uniform tension, bending, and bearing stresses where applicable. To provide a consistent approach, S0 is reserved for tension and compression, S1 and S2 are bending stresses in through-the-thickness (out of plane) and width (in-plane) directions, S3 is the bearing stress, and S4 is reserved for the second tension/compression stress for cases that have biaxial loading. Besides the standard loading types, all weight function based crack cases also offer general non-linear loading capability. In Table 2.2.1, such weight function based SIF models can be identified by their case names, which end with either "univariant WF" or "bivariant WF". There are a few special crack cases in the NASGRO library that are designed to work with remote displacement profiles instead of stress. The names of these particular cases end with the designation "displacement control".

Additional information regarding the SIF models may be found in Section 4 and Appendices C and D. The details of nonlinear stress input through tabular, polynomial, and external stress files are given in the "Weight Function Solution Options" section in Appendix C.

Table 2.2.1: Description of Crack Cases

ID	Name
	Through Cracks
TC01	Through crack at center of plate
TC02	Through crack at edge of plate
TC03	Through crack at hole (offset) in plate
TC05	Through crack(s) at hole in plate with row of holes
TC06	Through crack in hollow sphere

Continued on next page

Table 2.2.1: Description of Crack Cases (cont.)

ID	Name
TC07	Through crack (axial) in hollow cylinder
TC08	Through crack (circumferential) inthicn cylinder
TC09	Through crack at hole in plate under biaxial loading
TC10	Through crack (circumferential) at hole in hollow cylinder
TC11	Through crack (offset) in plate – univariant WF
TC12	Through crack at edge of plate – univariant WF
TC13	Through crack(s) at hole (offset) in plate, univariant WF
TC14	Through crack at edge of plate – displacement control
TC15	Through crack at edge of variable thickness plate – univariant WF
TC16	Through crack in thin curved stiffened panel with bulging
TC17	Through crack at edge notch in plate – univariant WF
TC18	Through crack(s) at (offset) embedded slot or elliptical hole in plate – univariant WF
TC19	Through crack at hole (offset) in plate with broken ligament – univariant WF
TC23	Two unequal through cracks at offset hole
TC24	Through crack (offset) in plate – displacement control
TC25	Through crack at edge rectangular cutout with rounded corners
TC26	Through crack at offset internal rectangular cutout with rounded corners
TC27	Through crack at hole in lug – univariant WF
TC28	Curved through crack at edge of plate – univariant WF
TC29	Offset curved through crack in plate – univariant WF
TC30	Through crack at hole in obliquely loaded and tapered lug - univariant WF
TC31	Through crack in L-section under remote loading – pre-corner
TC32	Through crack in L-section under remote loading – post-corner
TC33	Through crack growing toward a hole
TC34	Two collinear through cracks of unequal lengths
TC35	Through crack at edge of plate with one symmetric step change in thickness
TC37	Through crack in C-section under remote loading
TC38	Through crack at an interference fit hole
TC39	Through crack in T-section under remote loading
TC40	Through crack between two unequal holes (offset) in plate
TC43	Through crack(s) at hole (offset) in plate – univariant WF
	Corner Cracks
CC01	Quarter elliptical corner crack in plate
CC08	Quarter elliptical corner crack(s) at hole (offset) in plate – univariant WF
CC09	Quarter elliptical corner crack in plate - bivariant WF
CC10	Quarter elliptical corner crack at hole (offset) in plate - bivariant WF
CC11	Quarter elliptical corner crack in plate - univariant WF
CC12	Quarter elliptical corner crack at chamfer in plate - bivariant WF
CC13	Quarter elliptical corner crack at edge notch in plate
CC14	Quarter elliptical corner crack at (offset) embedded slot or elliptical hole in plate
CC15	Quarter elliptical corner crack at (offset) hole in plate with broken ligament
CC16	Corner crack(s) at a hole based on Fawaz-Anderson solution

Continued on next page

Table 2.2.1: Description of Crack Cases (cont.)

ID	Name
CC17	Two unequal corner cracks at a hole in a finite plate
CC18	Part elliptical corner crack at angled corner - bivariant WF
CC19	Quarter elliptical corner crack at hole in lug - univariant WF
CC20	Quarter elliptical corner crack in plate - displacement control
CC21	Corner crack at edge rectangular cutout with rounded corners
CC22	Corner crack at offset internal rectangular cutout with rounded corners
CC23	Corner crack at hole in obliquely loaded and tapered lug - univariant WF
CC24	Corner crack(s) at hole(s) in plate with row of holes
CC25	Corner crack at countersunk hole in infinite plate (Cronenberger solution)
CC26	Quarter elliptical corner crack at hole (offset) in plate - bivariant WF
	Surface Cracks
SC01	Semi-elliptical surface crack in plate
SC02	Semi-elliptical surface crack in plate – univariant WF
SC03	Semi-elliptical surface crack in pressurized sphere
SC04	Semi-elliptical surface crack (axial) in hollow cylinder – univariant WF
SC05	Semi-elliptical surface crack (circumferential) in hollow cylinder
SC06	Constant-depth surface crack (circumferential) in hollow cylinder – univariant WF
SC07	Semi-elliptical surface crack (circumferential) in solid cylinder
SC08	Semi-elliptical surface crack (circumferential) in threaded solid cylinder
SC09	Constant-depth surface crack (circumferential) in threaded solid cylinder
SC10	Constant-depth surface crack (circumferential) in threaded hollow cylinder
SC11	Semi-elliptical surface crack(s) at hole in plate
SC13	Semi-elliptical surface crack in bolt head fillet – shear bolt
SC14	Semi-elliptical surface crack in bolt head fillet – tension bolt
SC18	Semi-elliptical surface crack(s) (offset) at hole (offset) in plate – univariant WF
SC26	Surface crack at edge notch in plate
SC27	Surface crack at (offset) embedded slot or elliptical hole in plate
SC28	Surface crack at (offset) hole in plate with broken ligament
SC29	Semi-elliptical surface crack (offset) at hole (offset) in plate – bivariant WF
SC30	Semi-elliptical surface crack (offset) in plate – univariant WF
SC31	Semi-elliptical surface crack (offset) in plate – bivariant WF
SC32	Semi-elliptical surface crack at hole in lug – univariant WF
SC33	Semi-elliptical surface crack at center of plate – displacement control
SC34	External surface crack in a hollow cylinder – univariant WF
SC35	Semi-elliptical surface crack in a solid cylinder – univariant WF
SC36	Semi-elliptical surface crack (external circumferential) in sphere – univariant WF
SC37	Semi-elliptical surface crack(s) (offset) at hole (offset) in plate -– univariant WF
SC38	Semi-elliptical surface crack (offset) at hole (offset) in plate –- bivariant WF
	Embedded Cracks
EC04	Elliptical embedded crack (offset) in plate - bivariant WF
EC05	Elliptical embedded crack (offset) in plate - univariant WF

Continued on next page

Table 2.2.1: Description of Crack Cases (cont.)

ID	Name
	Hybrid Cracks
HC01	HC01 - corner crack and through crack at hole (offset)
	Data Tables
DT01	One-dimensional data table for a through crack (one tip)
DT02	Two-dimensional data table for a through crack (one tip)
DT03	Two-dimensional data table for a part-through crack (two tips)
DT04	Two-dimensional data table for one or two through-cracks (two tips)
	Stress Intensity Factor Tables
KT01	One-dimensional stress intensity factor table for a through crack (one tip)
KT02	Two-dimensional stress intensity factor table for a through crack (one tip)
KT03	Two-dimensional stress intensity factor table for a part-through crack (two tips)
KT04	Two-dimensional stress intensity factor table for one or two through-cracks (two tips)
	Polynomial Series
PS01	Polynomial series
	Standard Specimens
SS01	Middle crack tension specimen M(T)
SS02	Compact tension specimen C(T)
SS03	Disc-shaped compact tension specimen DC(T)
SS04	Arc-shaped tension specimen A(T)
SS05	Single edge crack bend specimen SE(B) – three-point bend
SS06	Single edge crack tension specimen SE(T) – constrained ends
SS07	Notched round bar specimen R-bar(T) – circumferential crack
SS08	Single edge notch tension specimen SEN(T) with semi-elliptical surface crack
SS09	Single edge notch tension specimen SEN(T) with quarter-elliptical corner crack
SS10	Single edge notch tension specimen SEN(T) with through crack
SS11	Quarter-elliptical corner crack at centered hole in plate
SS12	Eccentrically-loaded single edge crack tension specimen ESE(T)
SS13	Same as SC01, for use by NASMAT only
SS14	Same as SC17, for use by NASMAT only
	Superseded Solutions
TC04	Through crack at hole in lug
CC02	Quarter elliptical corner crack at hole (offset) in plate
CC03	Quarter elliptical corner crack at hole in lug
CC04	Quarter elliptical corner crack(s) at hole in plate
CC05	Corner crack in rectangular plate subjected to bivariant stress
CC07	Quarter elliptical corner crack at hole in plate
SC12	Semi-elliptical surface crack(s) at hole in lug
SC15	Surface crack in plate subjected to bivariant stress
SC17	Semi-elliptical surface crack (offset) in plate – univariant WF

Continued on next page

Table 2.2.1: Description of Crack Cases (cont.)

ID	Name
SC19	Semi-elliptical surface crack (offset) in plate – bivariant WF
EC01	Elliptical embedded crack in plate
EC02	Elliptical embedded crack (offset) in plate – univariant WF
BE02	Two through cracks of unequal length at opposite sides of hole (offset) in plate
BE03	Through crack and corner crack at opposite sides of hole (offset) in plate

2.2.4 Transition of Crack Geometry

Crack growth analysis is usually conducted on part-through cracks, such as surface or corner crack in a plate. As the crack grows, the depth of the crack may exceed the thickness before the crack becomes unstable. In such instances, growth will continue using the corresponding through crack and then the crack will grow some more before becoming critical. Table 2.2.2 shows the transition relation between crack cases (with details given in Appendix D).

Table 2.2.2: Transition Relationship between Crack Cases (Details in Appendix D)

From	To	Condition/Comment
TC03	TC02	
TC11	TC12	Either crack tip can set off the transition
TC23	TC19	Either crack tip can set off the transition
TC24	TC14	
TC29	TC28	
TC31	TC32	
TC33	TC13	
TC34	TC11	
TC37	TC37	From first flange to web and to second flange
TC39	TC39	From flange to flange & web
CC01	TC02 or TC28	
CC02	TC03	
CC03	TC04	
CC04	TC03	Occurs only if number of cracks=1
CC05	TC12	Uses averaged unvariant stresses in TC12
CC07	TC03	Occurs only if number of cracks=1
CC08	TC13 or TC43	
CC09	TC12 or TC28	
CC10	TC13	
CC11	TC12 or TC28	Either crack tip can set off the transition
CC12	TC12	
CC13	TC17	

Continued on next page

Table 2.2.2: Transition Relationship between Crack Cases (cont.)

From	To	Condition/Comment
CC14	TC18	
CC15	TC19	
CC16	TC03 or TC23	
CC17	HC01 or TC23	
CC18	CC12	
CC19	TC27	
CC21	TC25	
CC22	TC26	
CC23	TC30	
CC24	TC05	
CC26	TC13	
SC01	TC01	
SC02	TC01	Uses equivalent stresses in TC01
SC03	TC06	S_1 should be zero
SC04	TC07	Uses equivalent stresses in TC07
SC05	TC08	Both external & internal cracks undergo transition
SC11	TC03	Occurs only if number of cracks=1
SC12	TC04	Occurs only if number of cracks=1
SC15	TC11	
SC17	CC11, TC11, or TC12	
SC18	CC08 or TC13	
SC19	CC09, TC11, or TC12	
SC26	CC13 or TC17	
SC27	CC14 or TC18	
SC28	CC15 or TC19	
SC29	CC10 or TC13	
SC30	CC11, TC11, TC12 TC28, or TC29	
SC31	CC09, TC11, TC12, or TC29	
SC32	CC19 or TC27	
SC37	CC08 or TC43	
SC38	CC26 or TC43	
EC01	TC01	
EC02	SC30	
EC04	SC31, CC09, TC11, or TC12	Either crack tip can set off the transition
EC05	SC30, CC11, TC11, or TC12	Either crack tip can set off the transition
HC01	CC15 or TC23	
SS08	SS10	
SS09	SS10	
SS11	TC03	

Whenever nonlinear stresses are present in a part-through crack model, the statically equivalent tension and bending loads are computed and the corresponding nominal stresses S0, S1 are obtained for use in the through crack model to which the part-through crack transitions. Numerical integration is performed over the cross section of the geometry in use. In some cases such as CC05 to TC12, the bivariant stress field is integrated across the thickness but the variation along width is preserved.

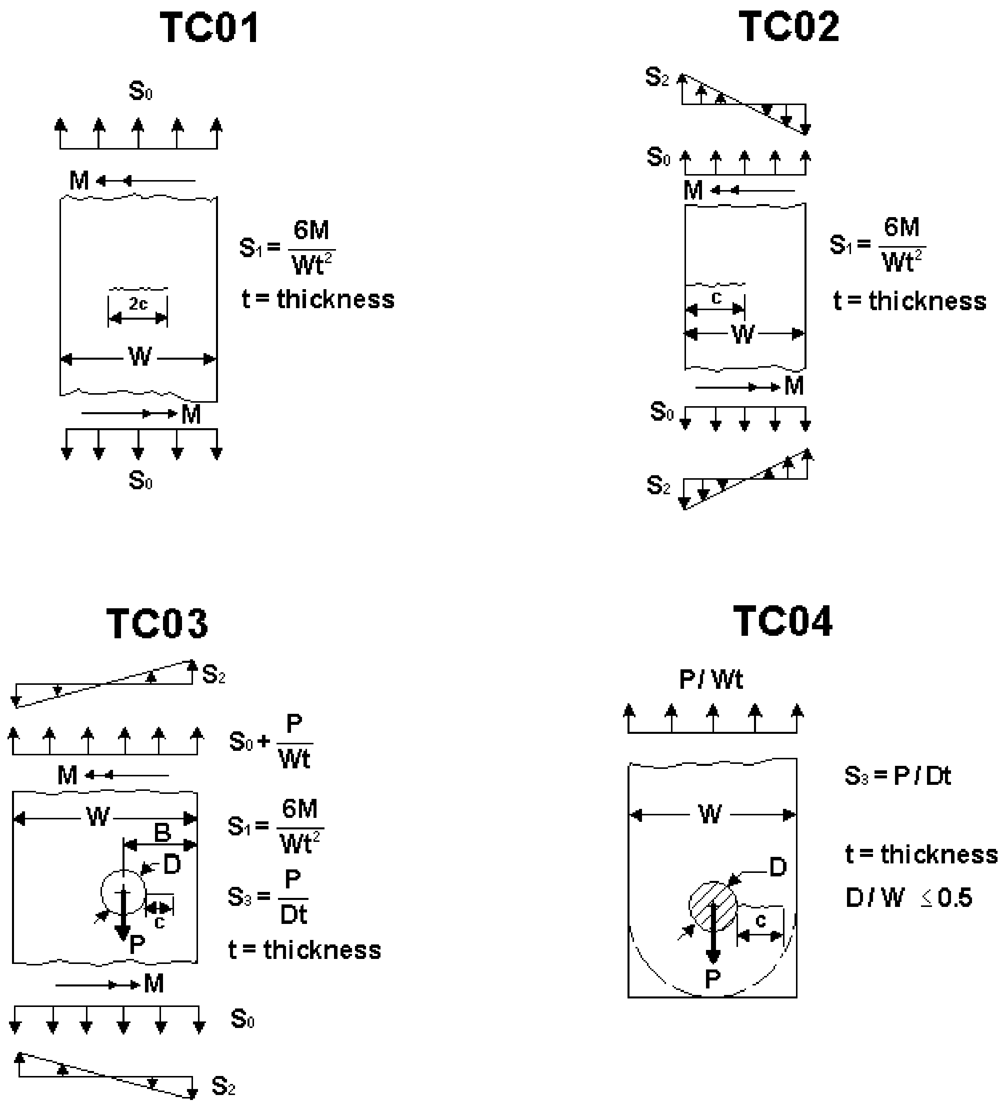
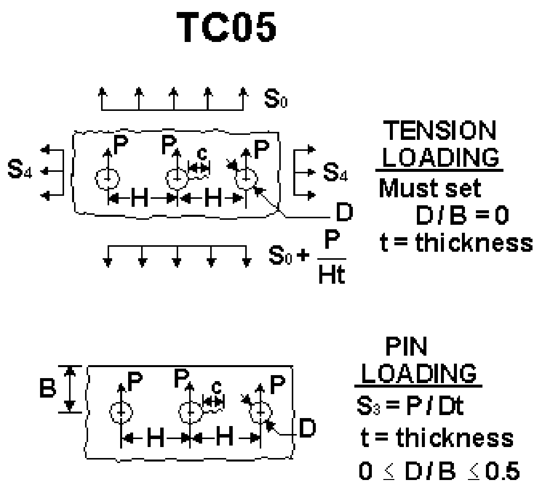
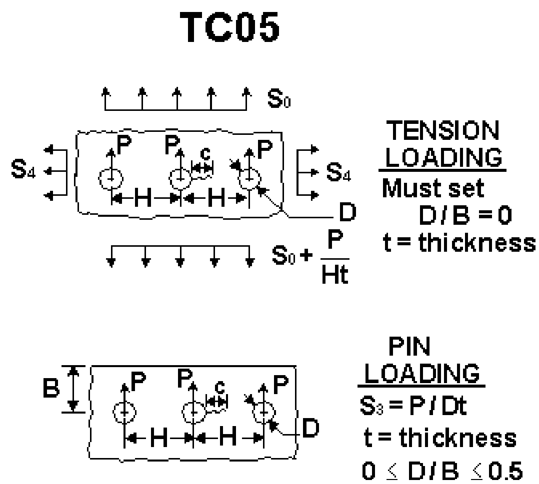


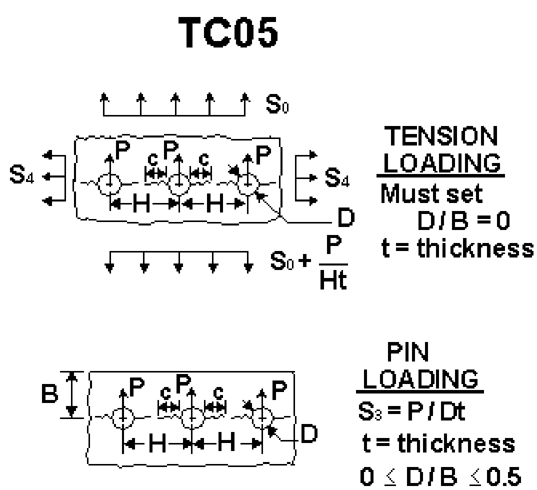
Figure 2.2.4: Through crack cases TC01, TC02, TC03, and TC04



(a) A single crack



(b) Two cracks



(c) Two cracks at each hole

Figure 2.2.5: Through crack case TC05

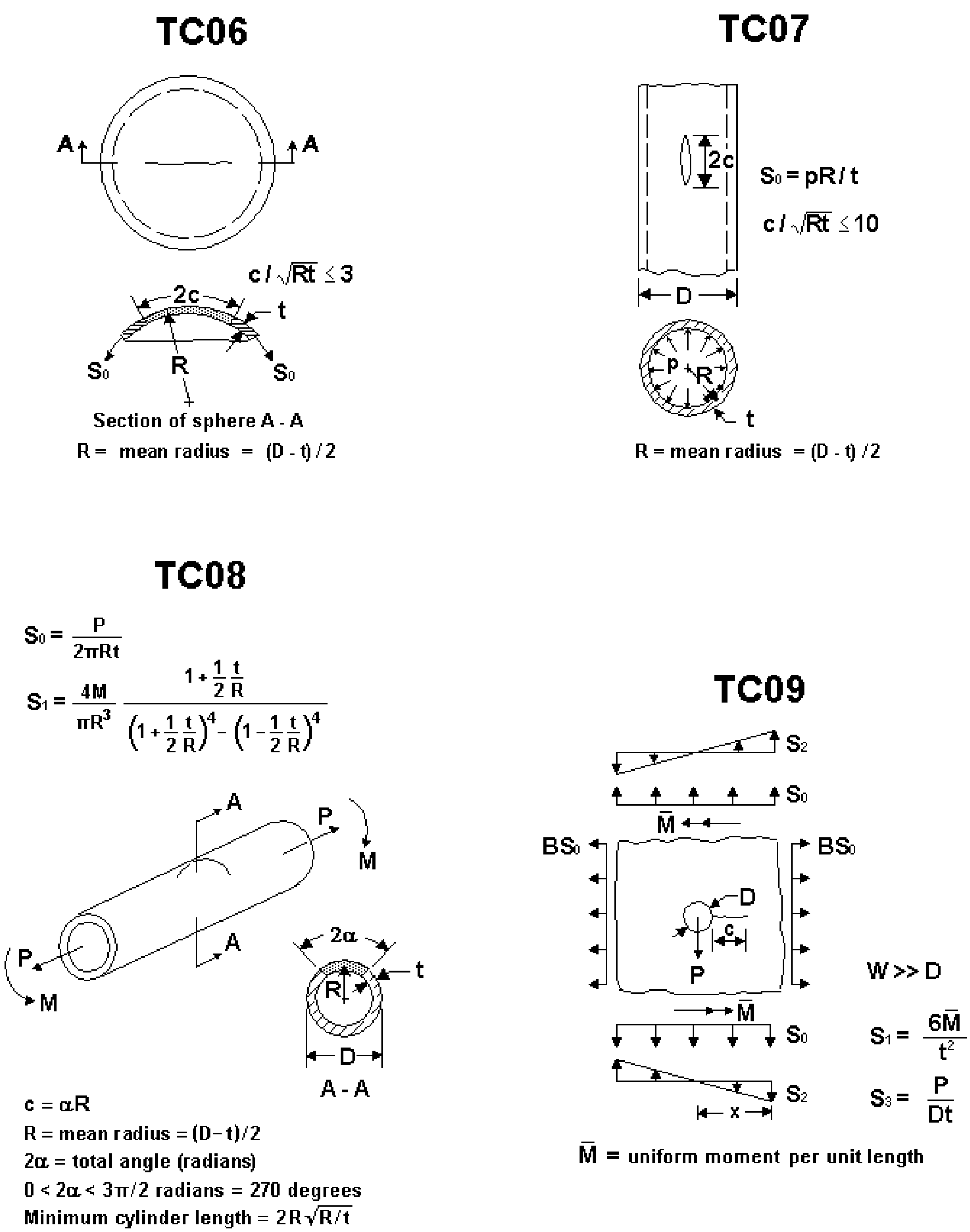


Figure 2.2.6: Through crack cases TC06, TC07, TC08, and TC09

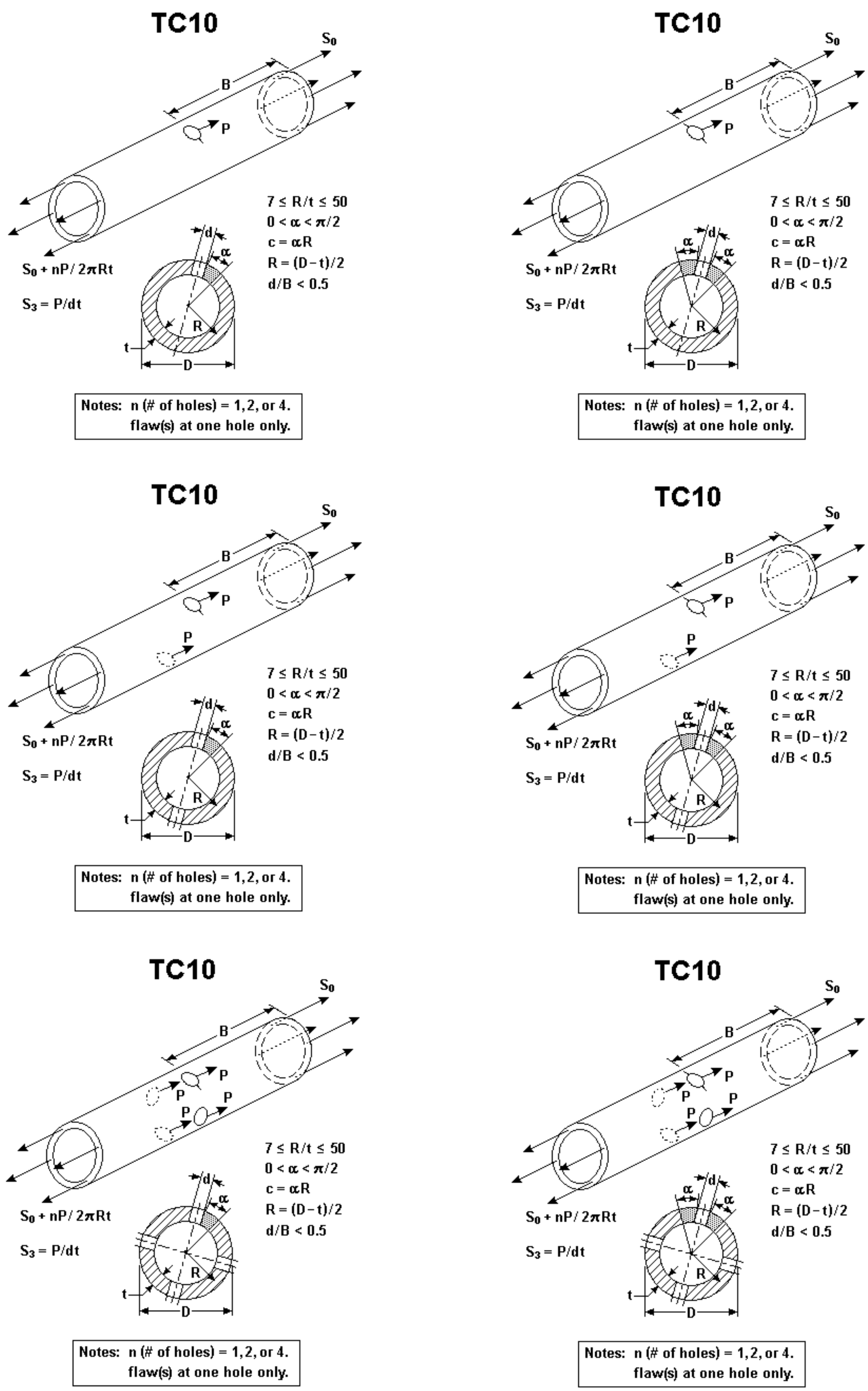


Figure 2.2.7: Through crack case TC10

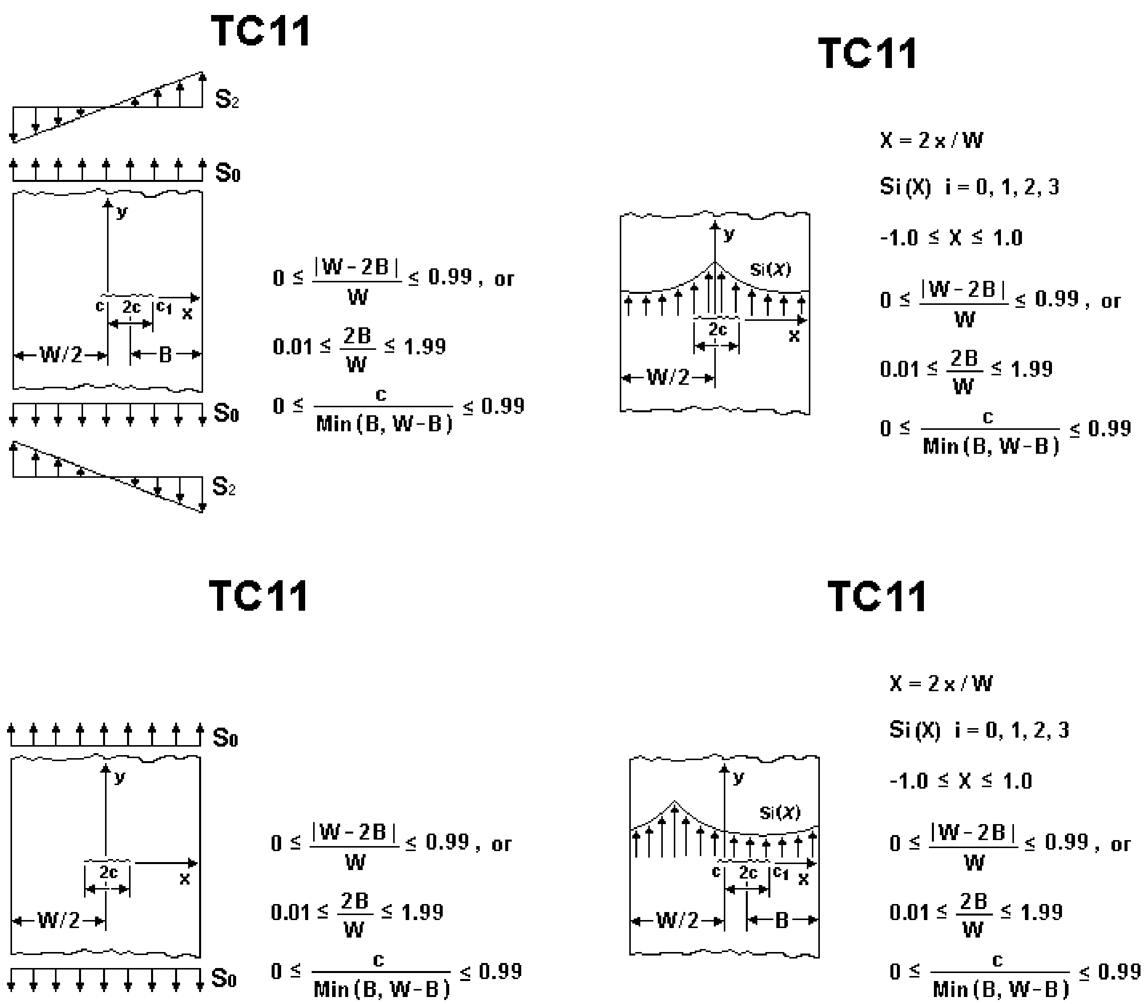


Figure 2.2.8: Through crack case TC11

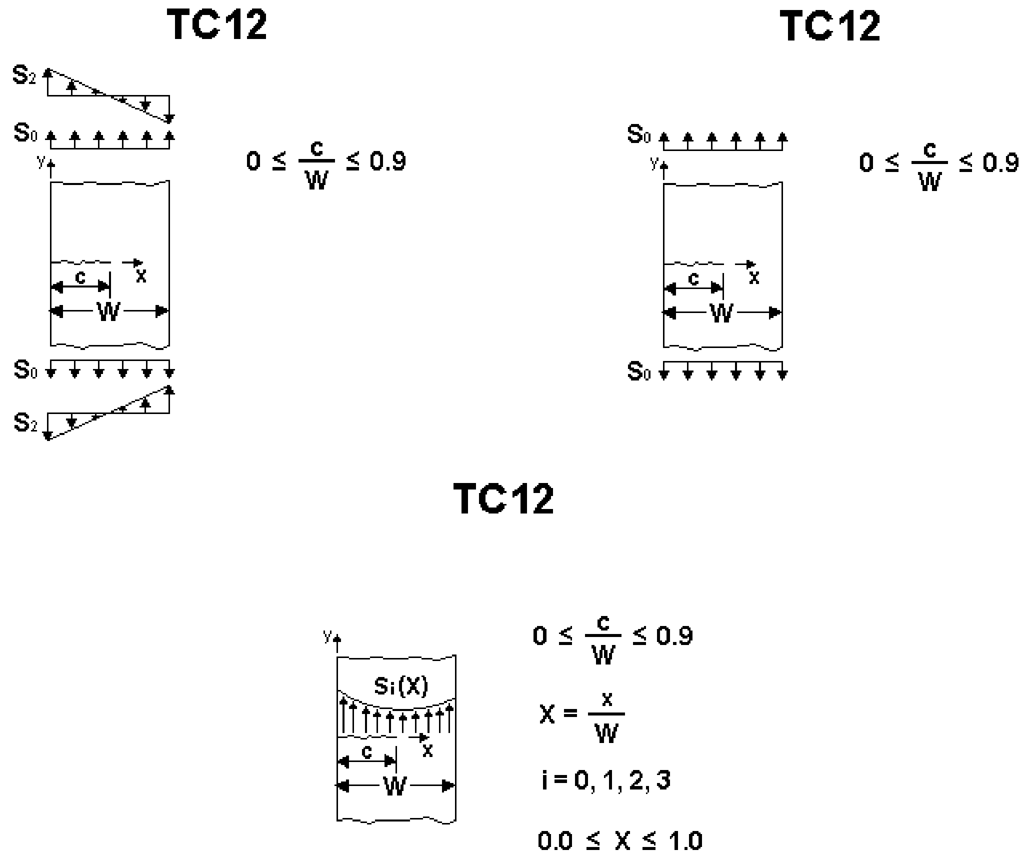


Figure 2.2.9: Through crack case TC12

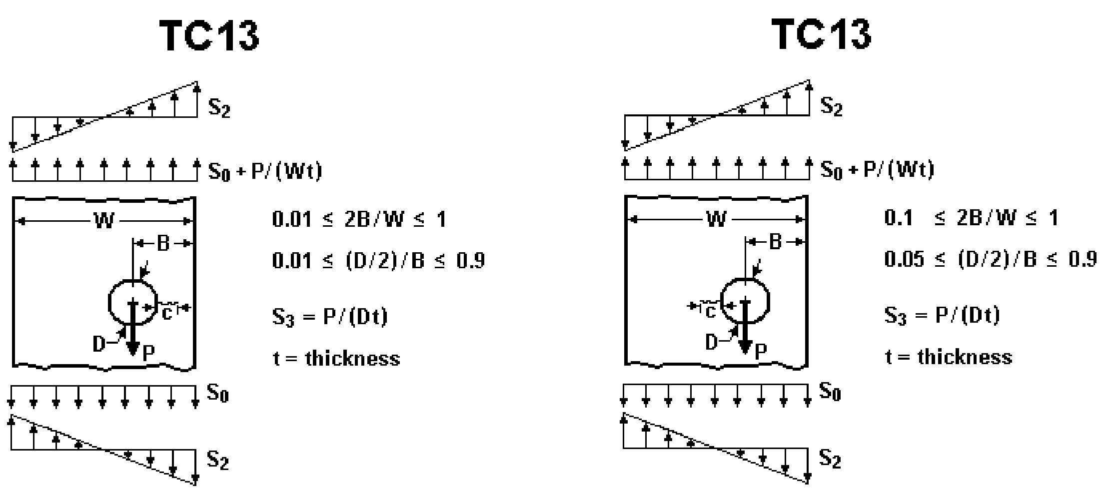


Figure 2.2.10: Through crack case TC13

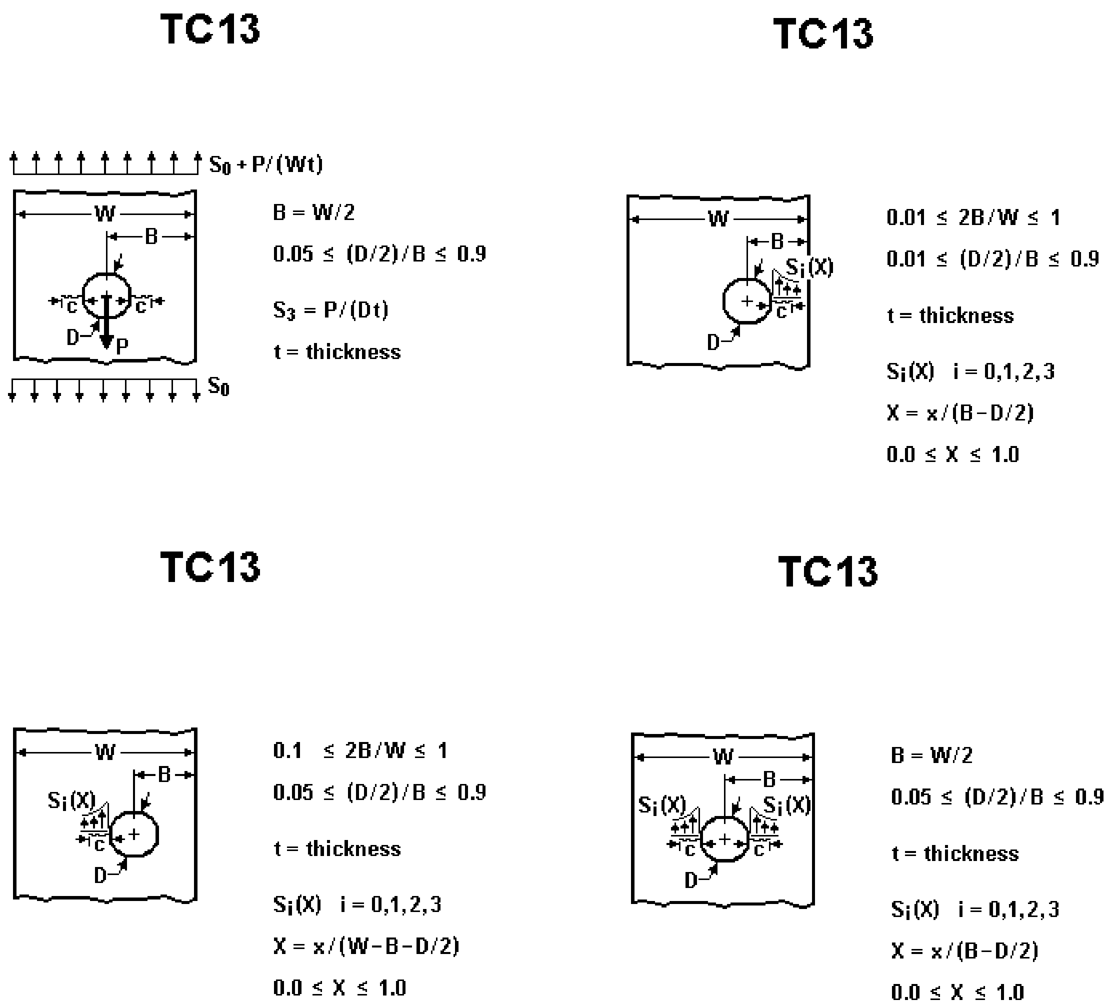


Figure 2.2.11: Through crack case TC13 (cont)

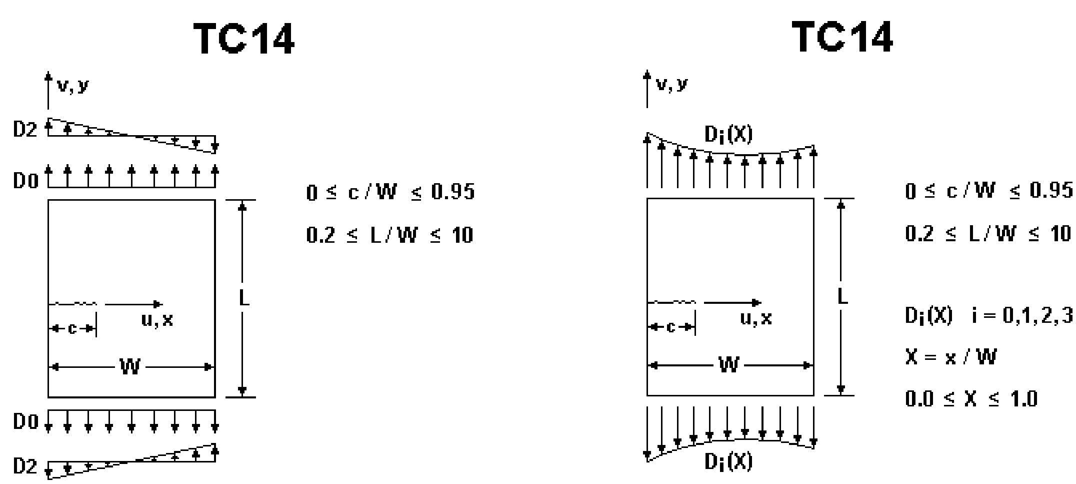


Figure 2.2.12: Through crack case TC14

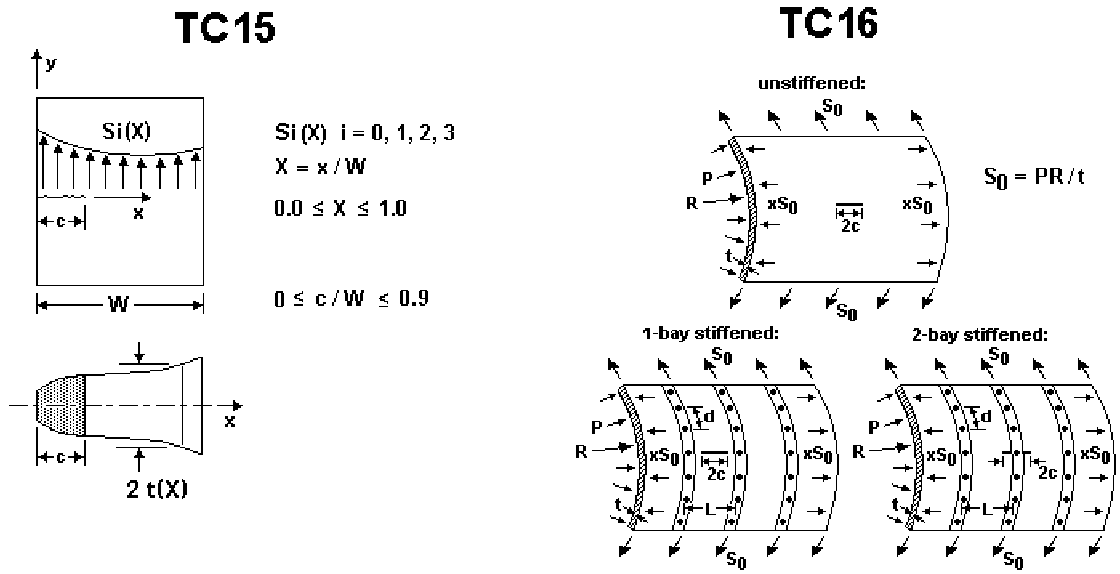


Figure 2.2.13: Through crack cases TC15 and TC16

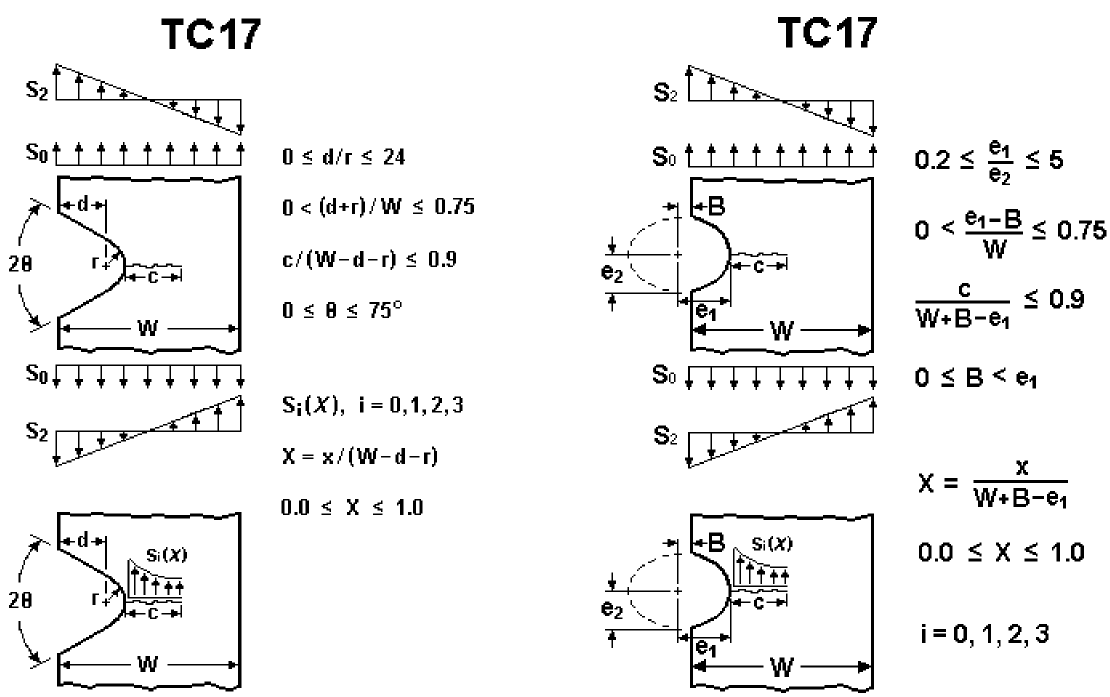


Figure 2.2.14: Through crack case TC17

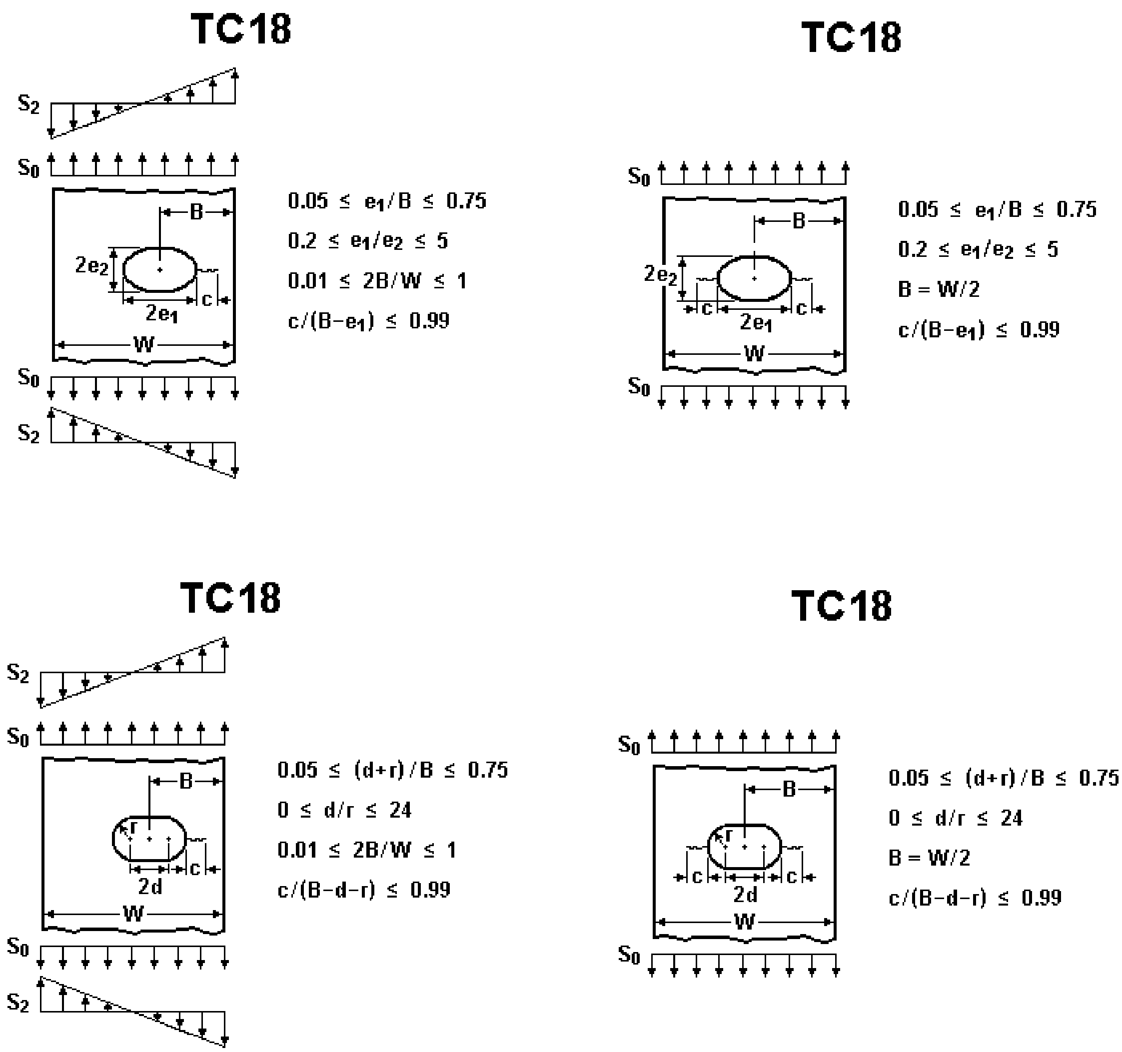


Figure 2.2.15: Through crack case TC18

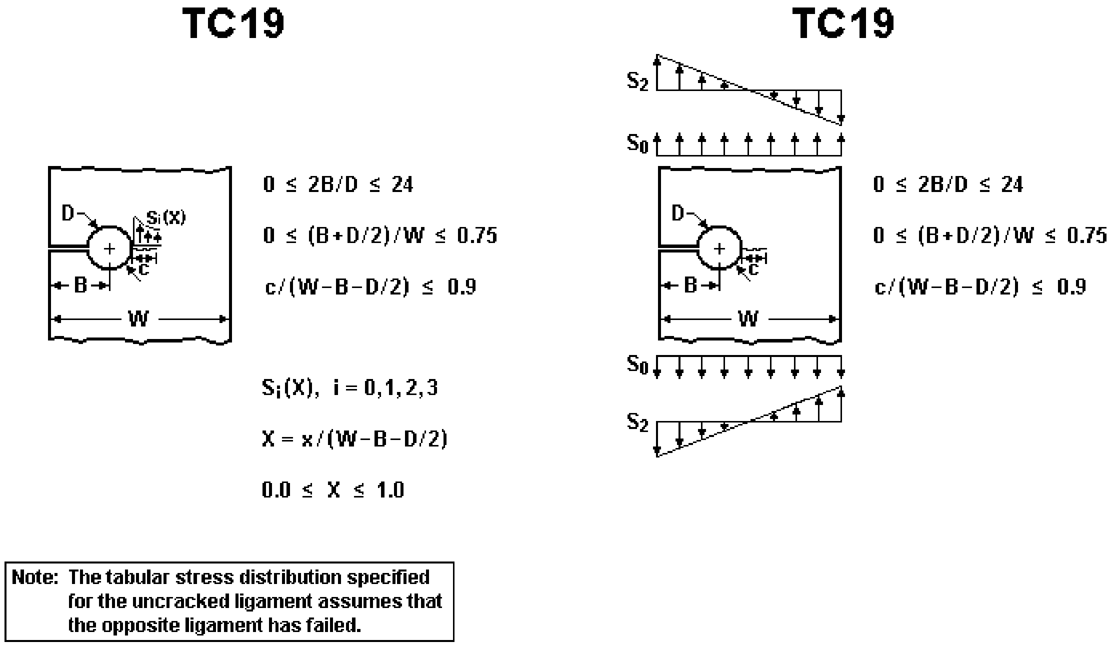


Figure 2.2.16: Through crack case TC19

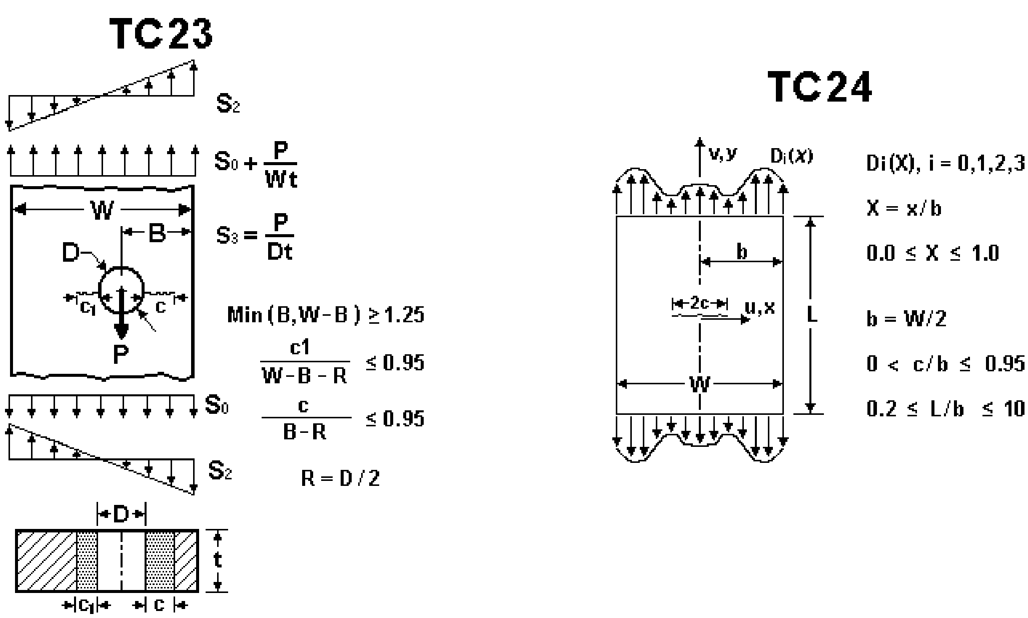
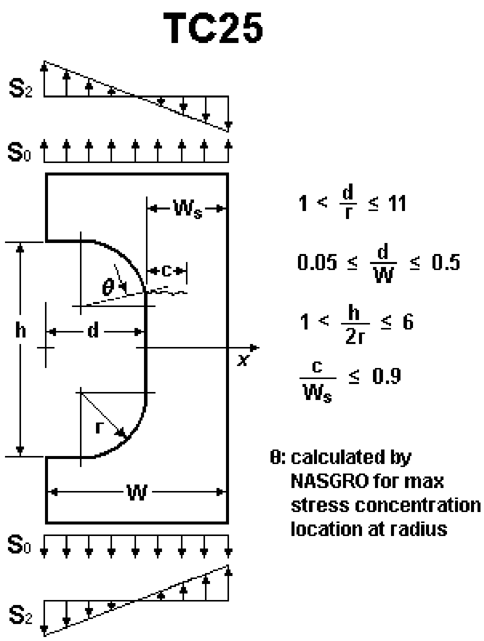


Figure 2.2.17: Through crack cases TC23 and TC24



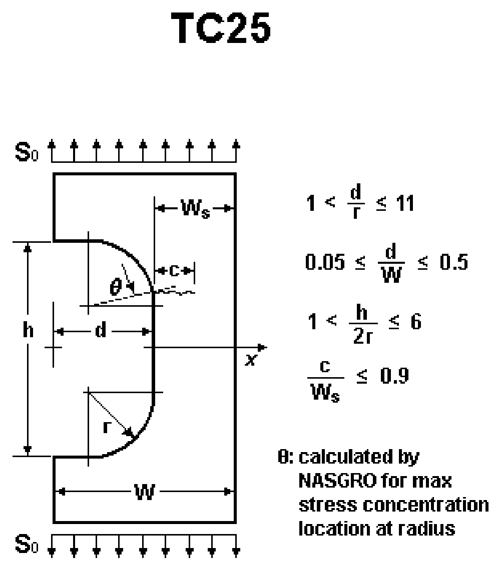


Figure 2.2.18: Through crack case TC25

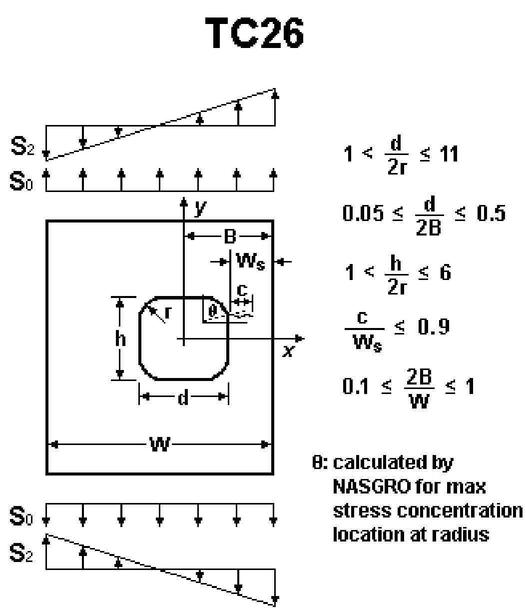


Figure 2.2.19: Through crack case TC26

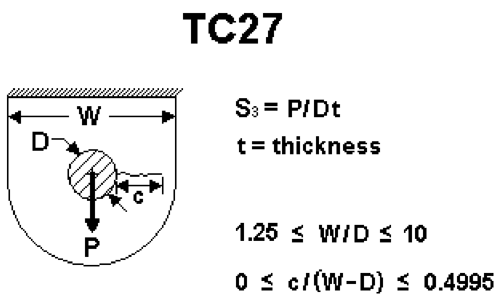


Figure 2.2.20: Through crack case TC27

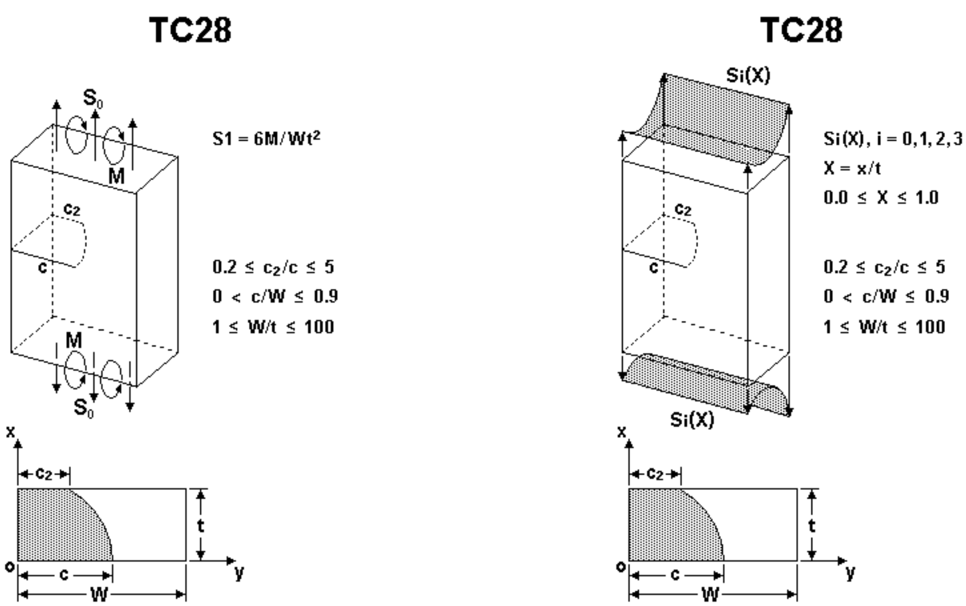


Figure 2.2.21: Through crack case TC28

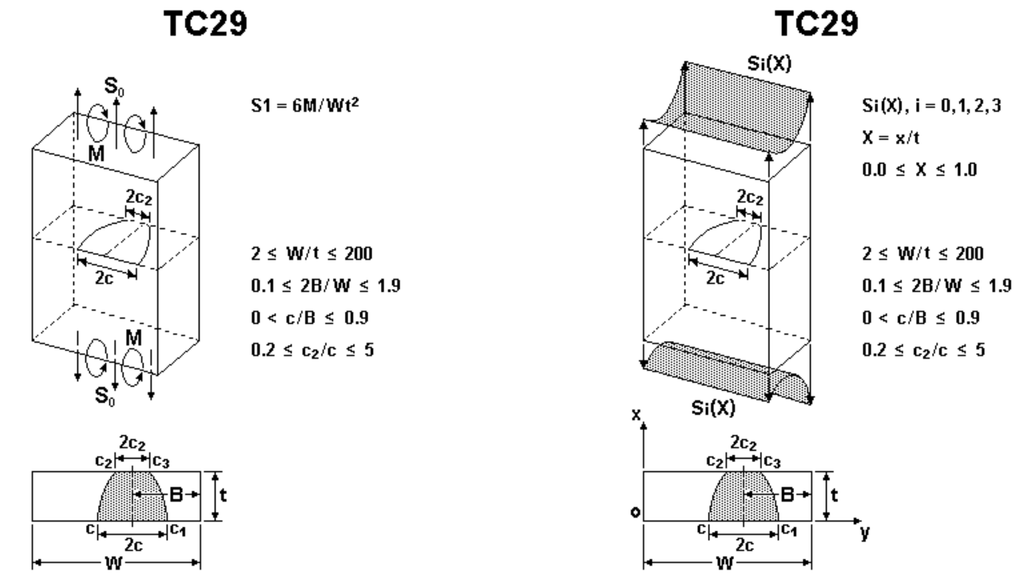


Figure 2.2.22: Through crack case TC29

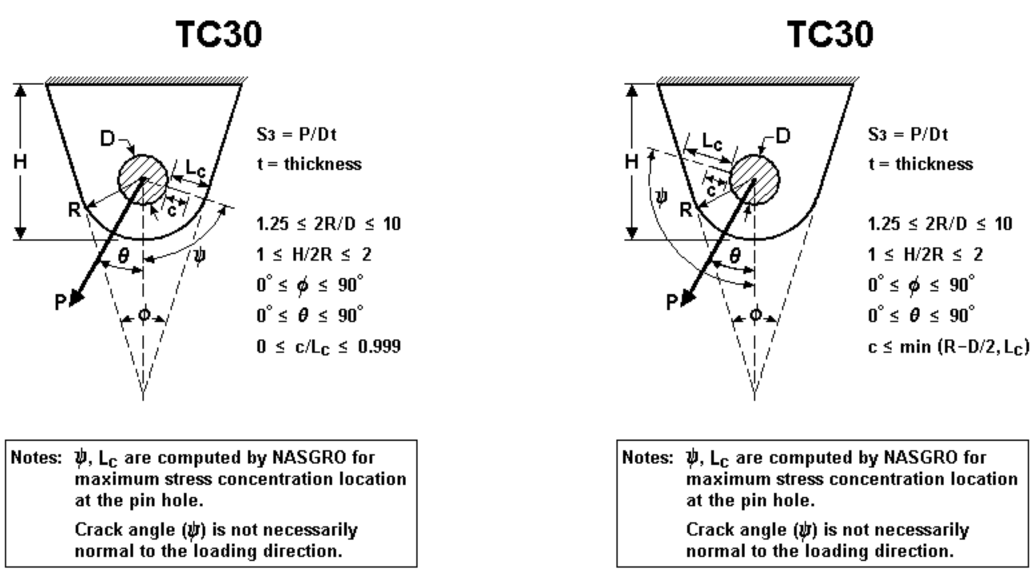


Figure 2.2.23: Through crack case TC30

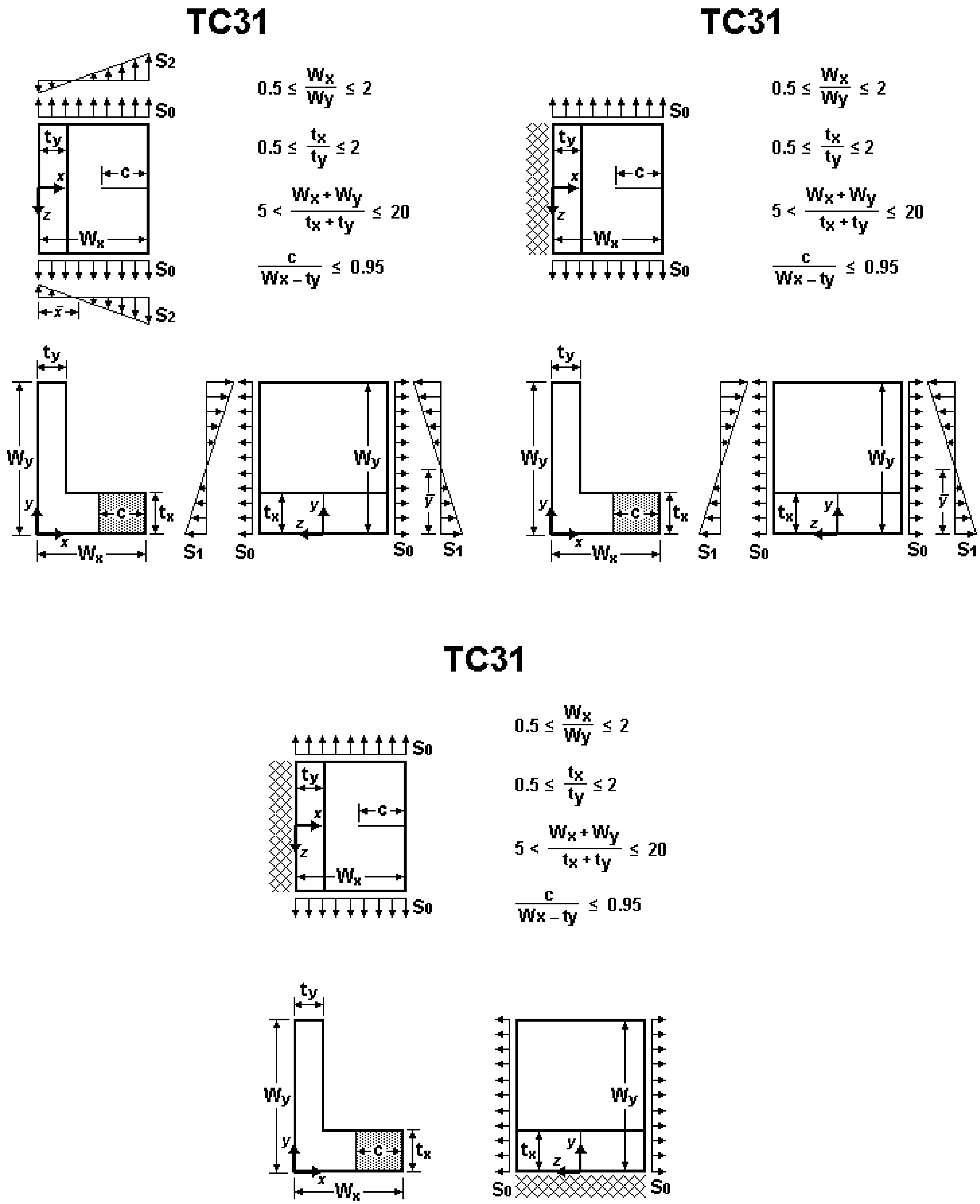


Figure 2.2.24: Through crack case TC31

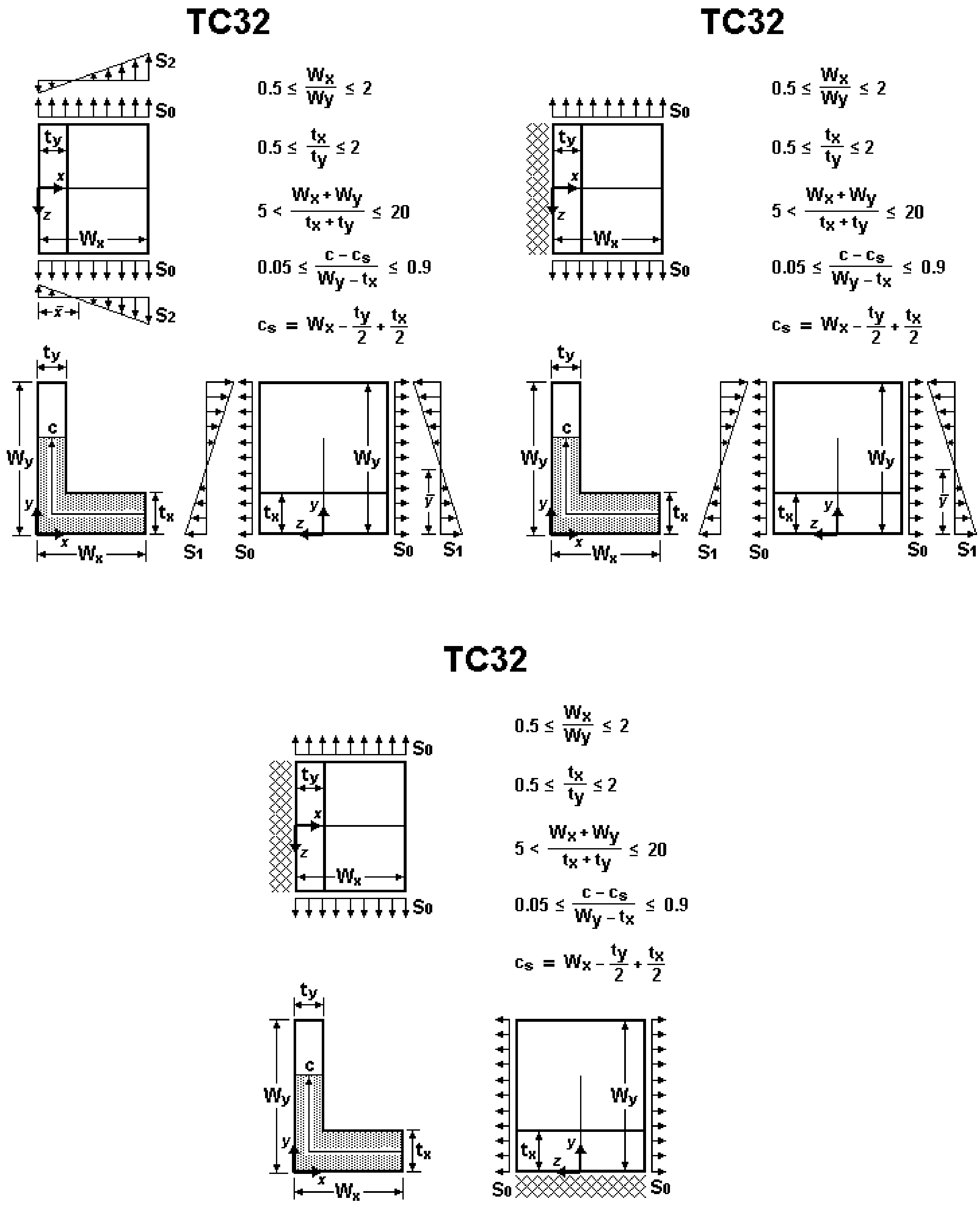


Figure 2.2.25: Through crack case TC32

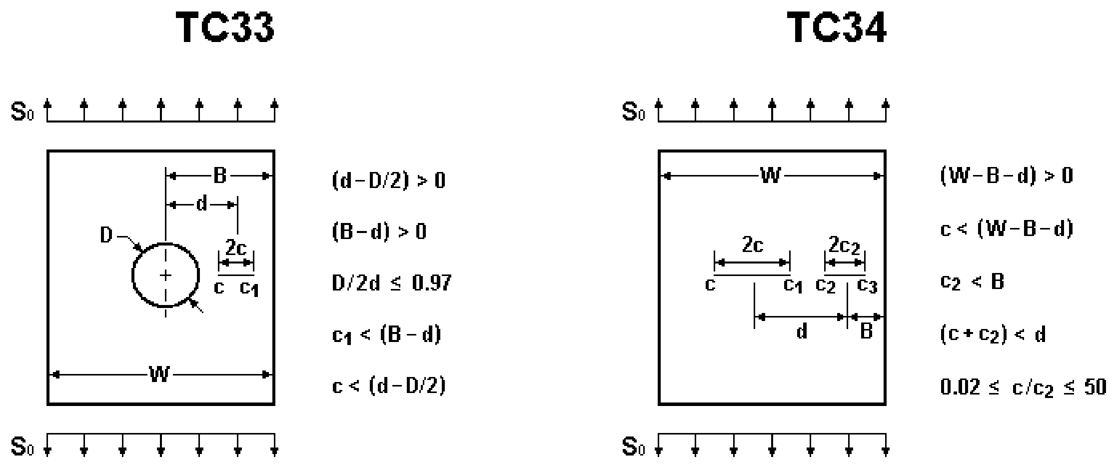


Figure 2.2.26: Through crack cases TC33 and TC34

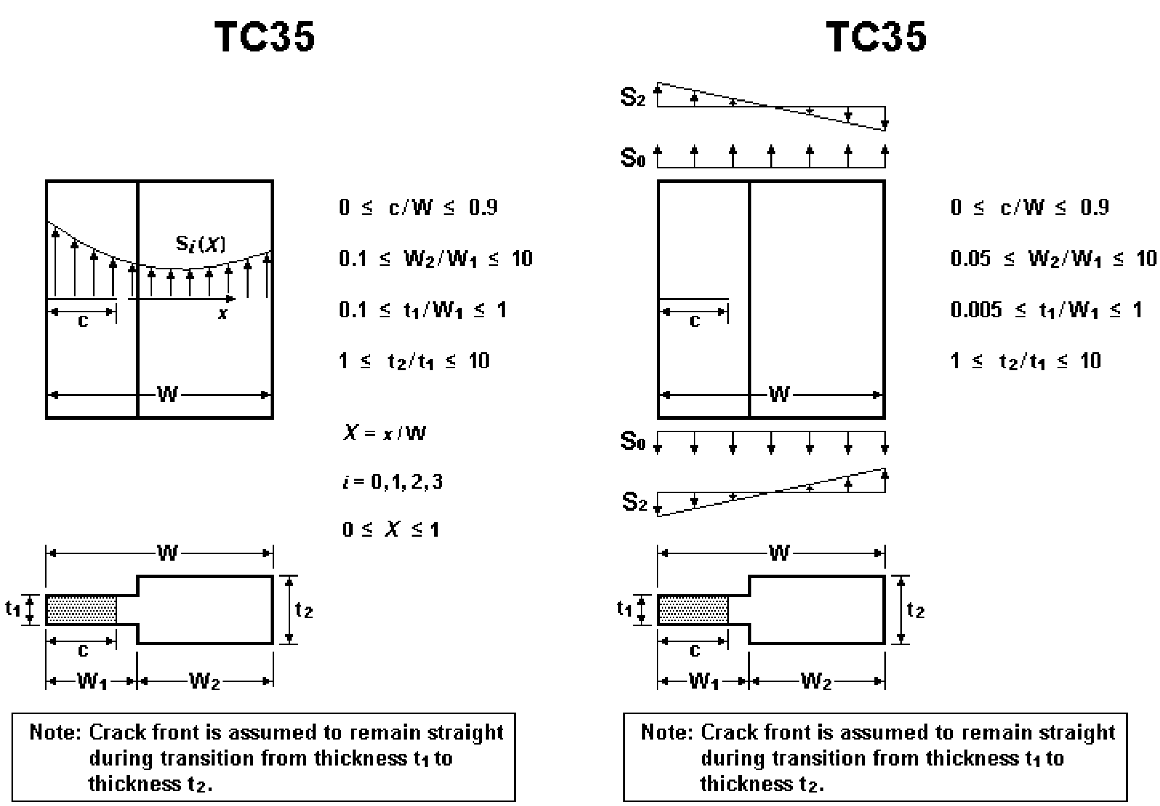


Figure 2.2.27: Through crack cases TC35

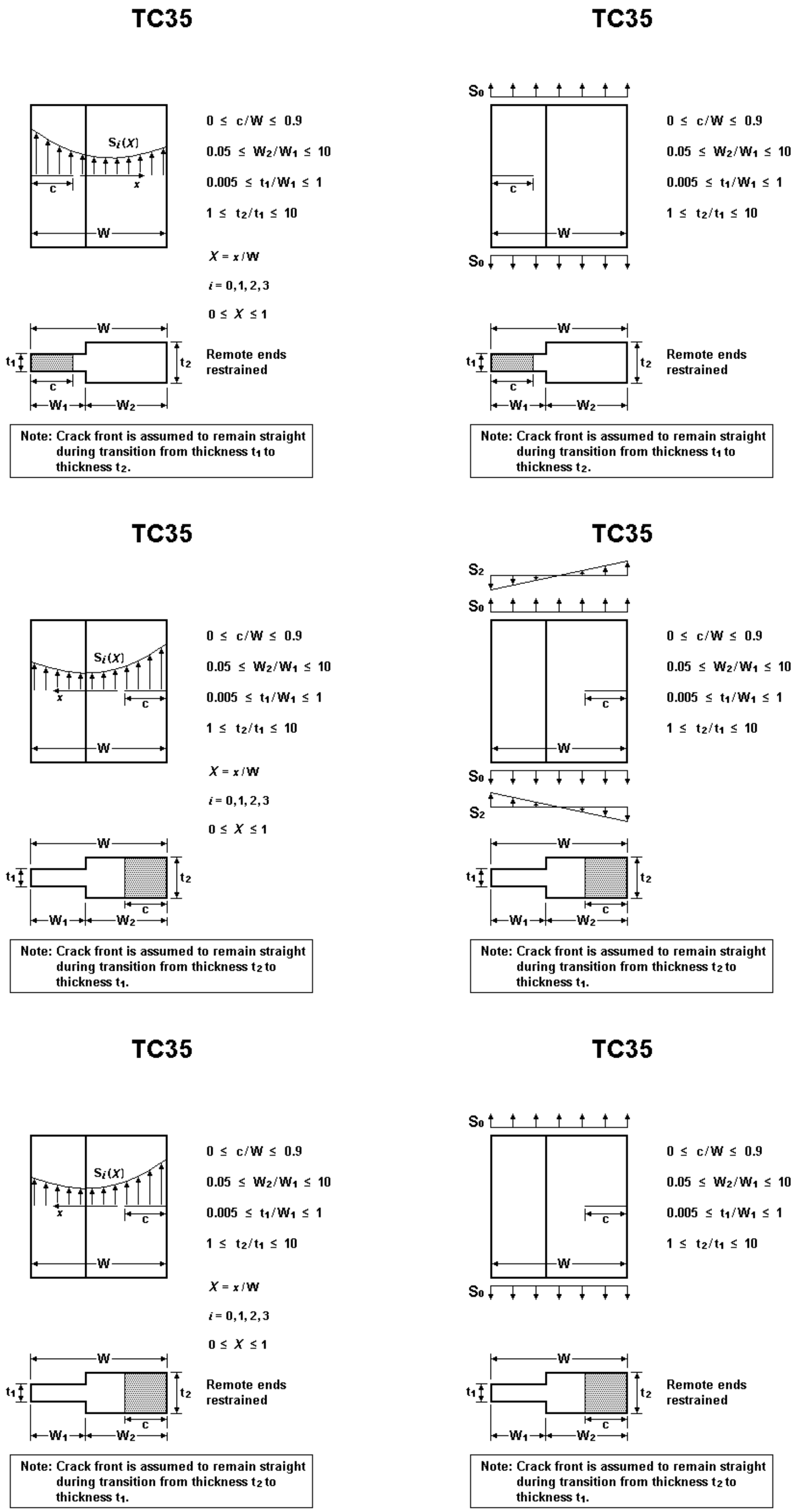


Figure 2.2.28: Through crack case TC35 (cont)

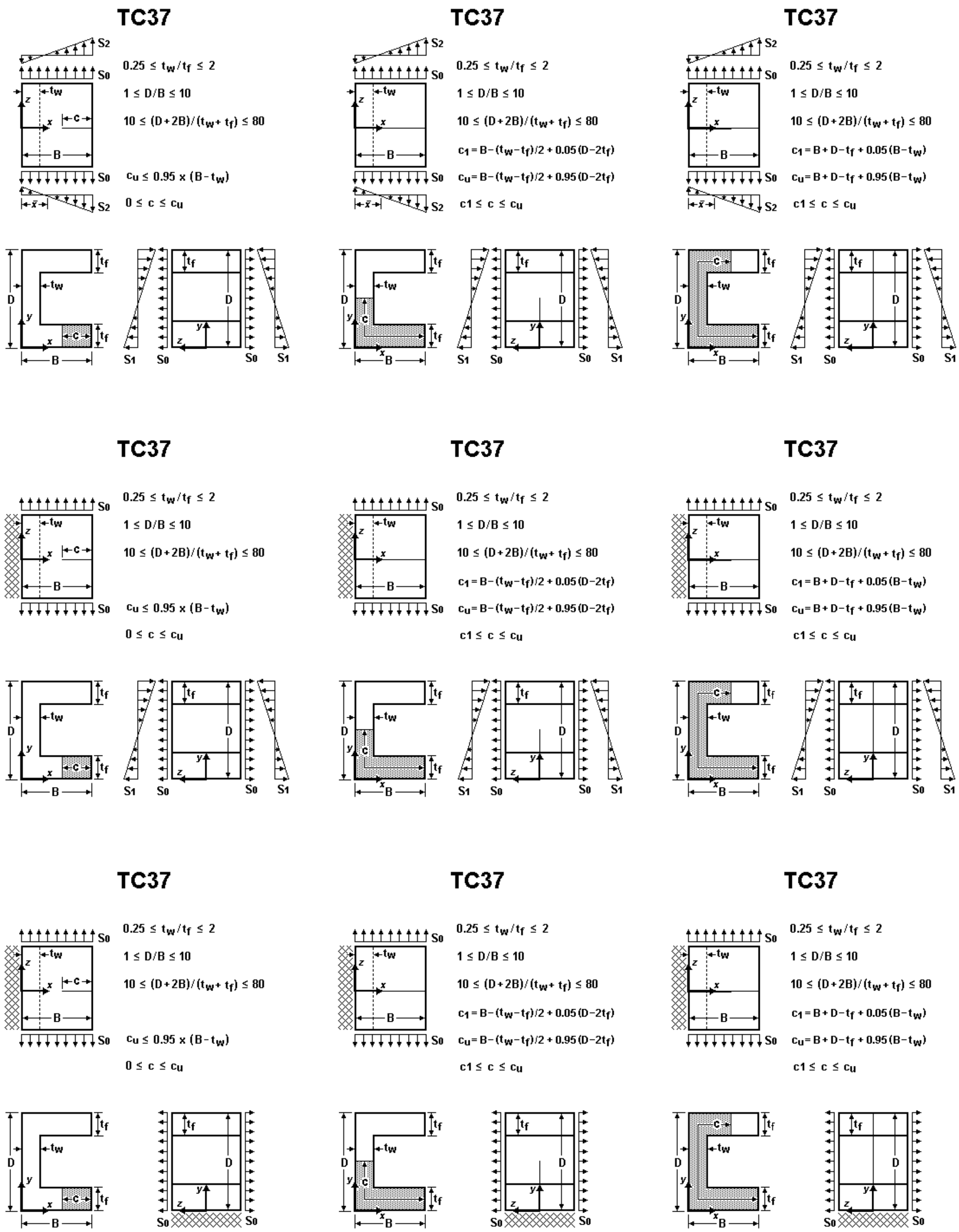


Figure 2.2.29: Through crack case TC37

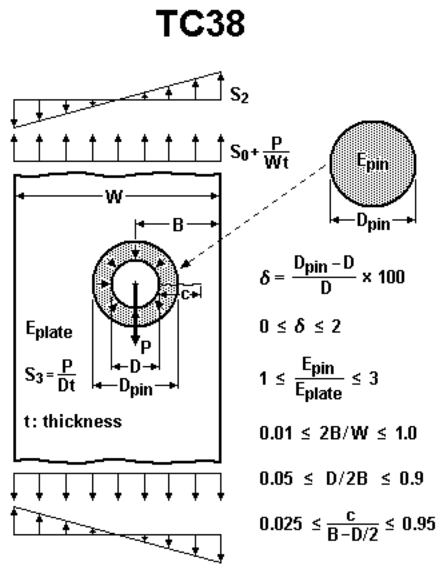


Figure 2.2.30: Through crack case TC38

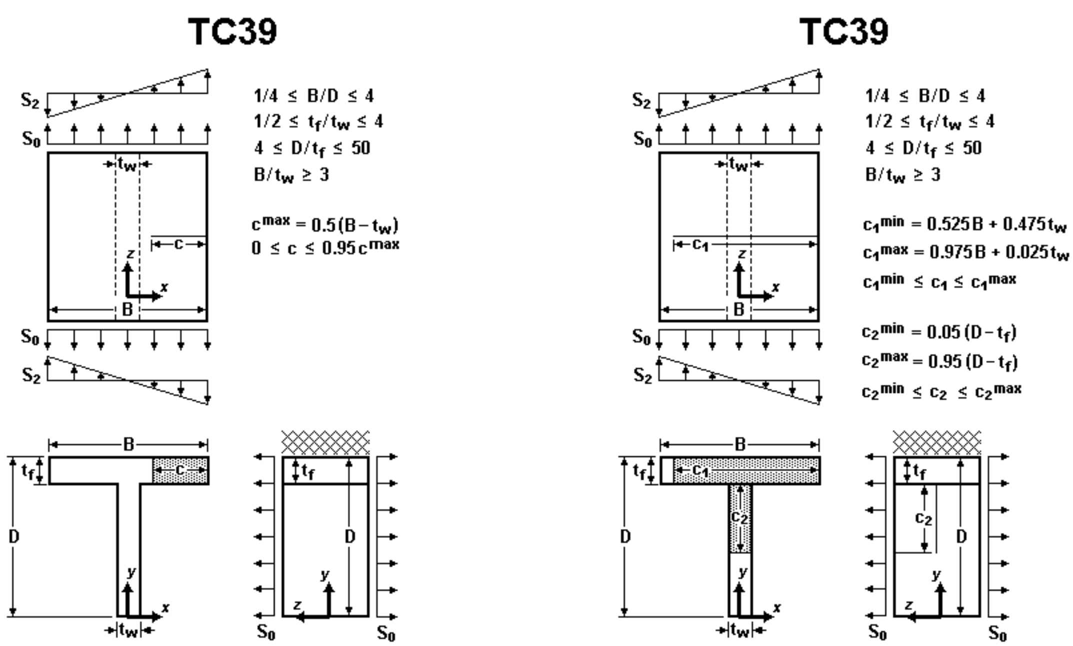
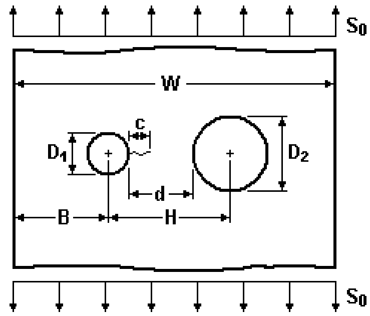


Figure 2.2.31: Through crack case TC39

TC40



$1/64 \le D_1/D_2 \le 64$

$d = H - (D_1 + D_2)/2$

$1/25 \le d/(D_1 + D_2) \le 5$

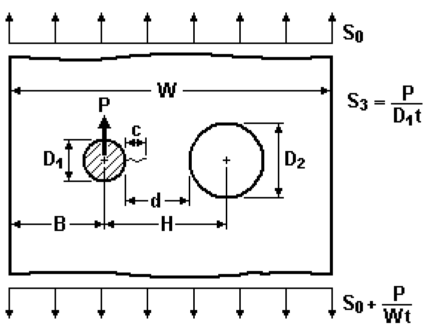
$1 \le B/D_1$

$1 \le (W - B - H)/D_2$

$0 \le c/d \le 0.99$

t: plate thickness

TC40



$1/64 \le D_1/D_2 \le 1$

$d = H - (D_1 + D_2)/2$

$1/25 \le d/(D_1 + D_2) \le 5$

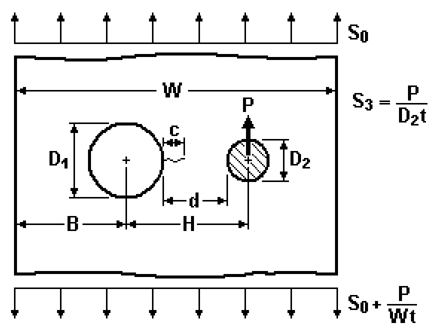
$1 \le B/D_1$

$1 \le (W - B - H)/D_2$

$0 \le c/d \le 0.99$

t: plate thickness

TC40



$1 \le D_1/D_2 \le 64$

$d = H - (D_1 + D_2)/2$

$1/25 \le d/(D_1 + D_2) \le 5$

$1 \le B/D_1$

$1 \le (W - B - H)/D_2$

$0 \le c/d \le 0.99$

t: plate thickness

Figure 2.2.32: Through crack case TC40

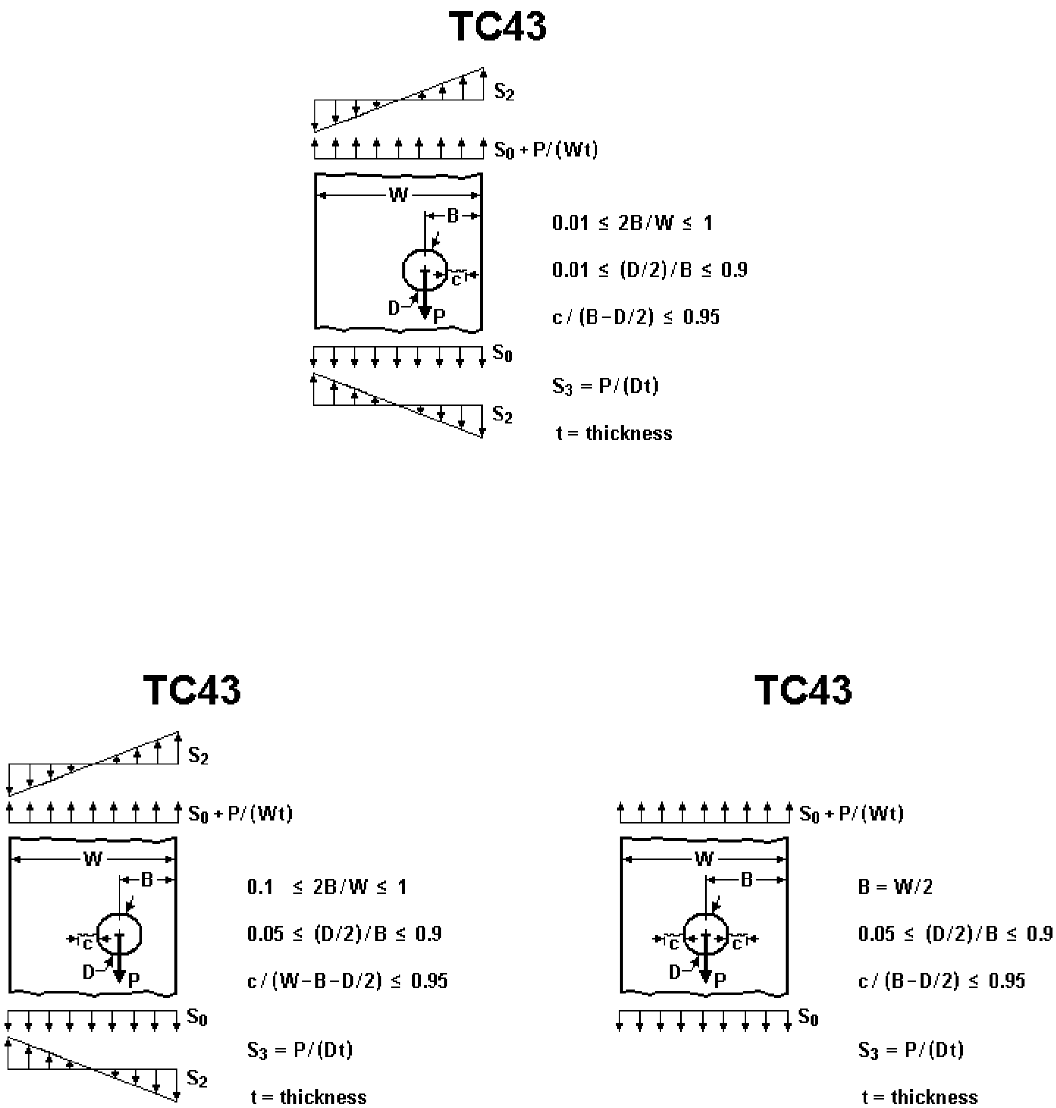
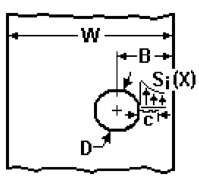


Figure 2.2.33: Through crack case TC43

TC43



$0.01 \le 2B/W \le 1$

$0.01 \le (D/2)/B \le 0.9$

$c/(B-D/2) \le 0.95$

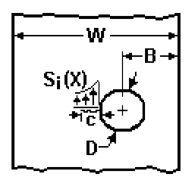
t = thickness

$S_i(X) \quad i = 0,1,2,3$

$X = x/(B-D/2)$

$0.0 \le X \le 1.0$

TC43



$0.1 \le 2B/W \le 1$

$0.05 \le (D/2)/B \le 0.9$

$c/(W-B-D/2) \le 0.95$

t = thickness

$S_i(X) \quad i = 0,1,2,3$

$X = x/(W-B-D/2)$

$0.0 \le X \le 1.0$

Figure 2.2.34: Through crack case TC43 (cont)

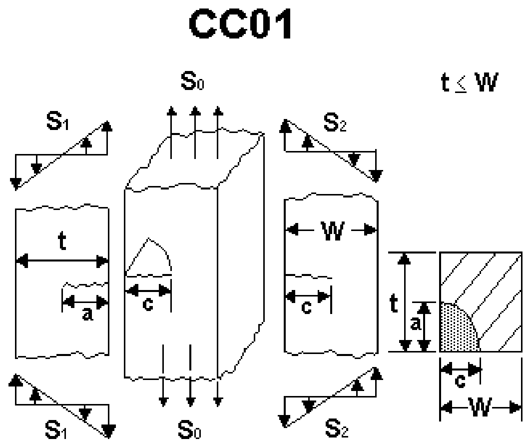


Figure 2.2.35: Corner crack case CC01

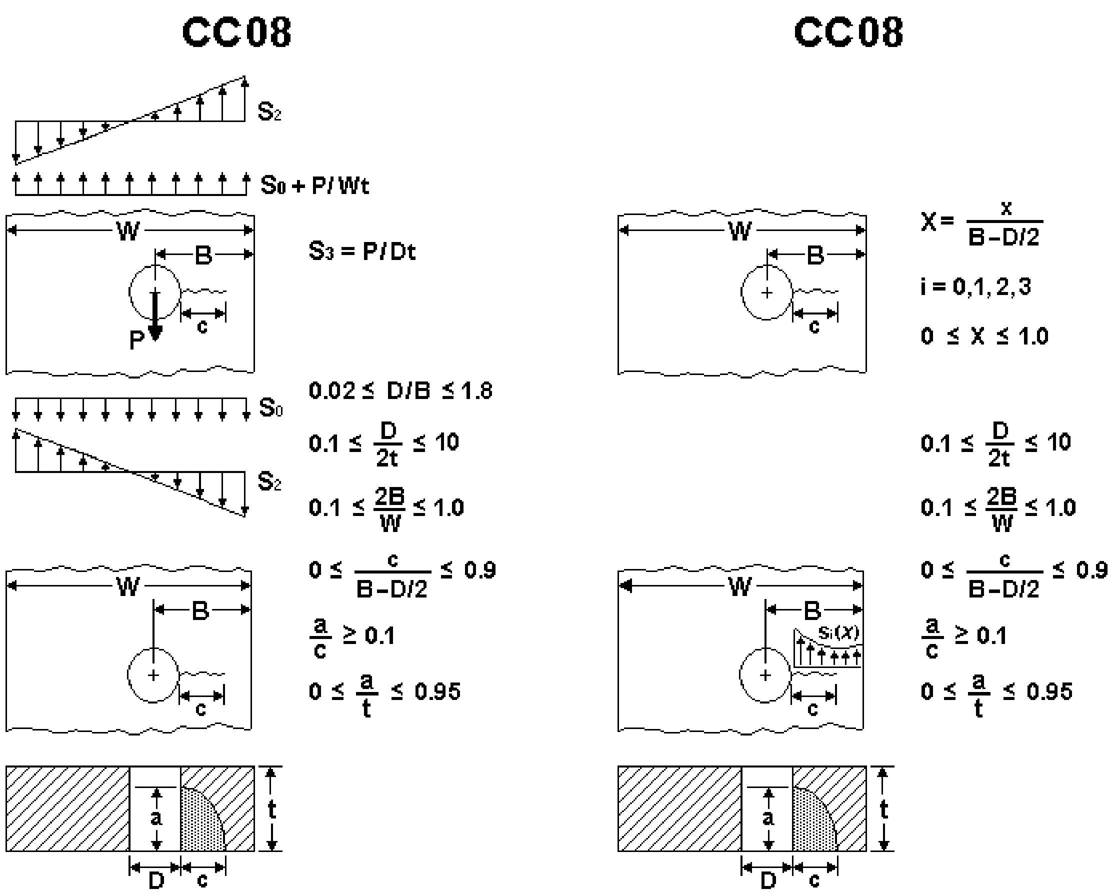


Figure 2.2.36: Corner crack case CC08

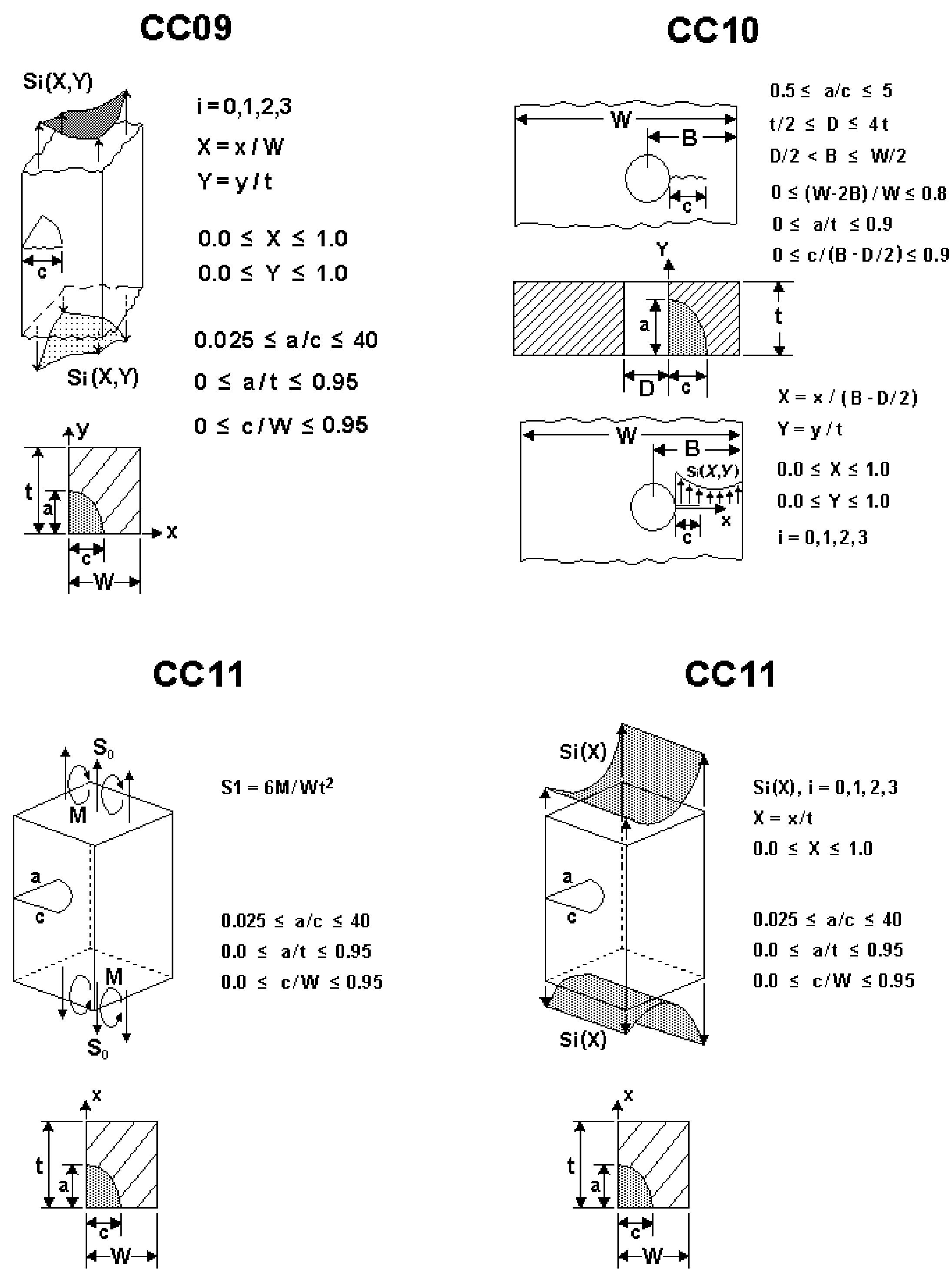


Figure 2.2.37: Corner crack cases CC09, CC10, and CC11

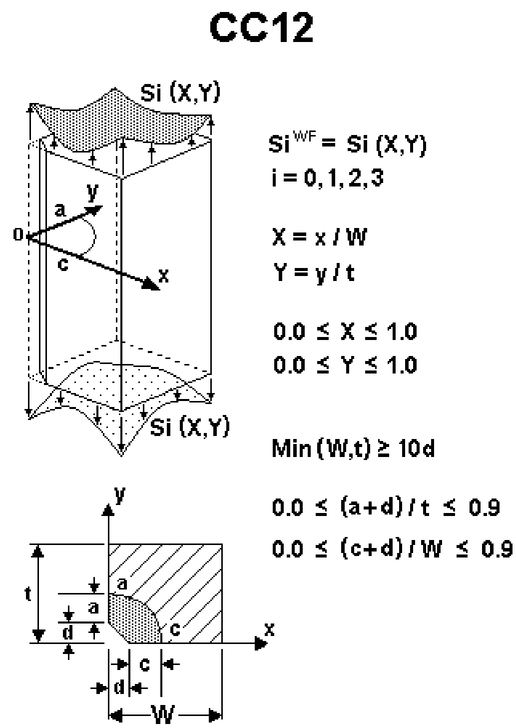


Figure 2.2.38: Corner crack case CC12

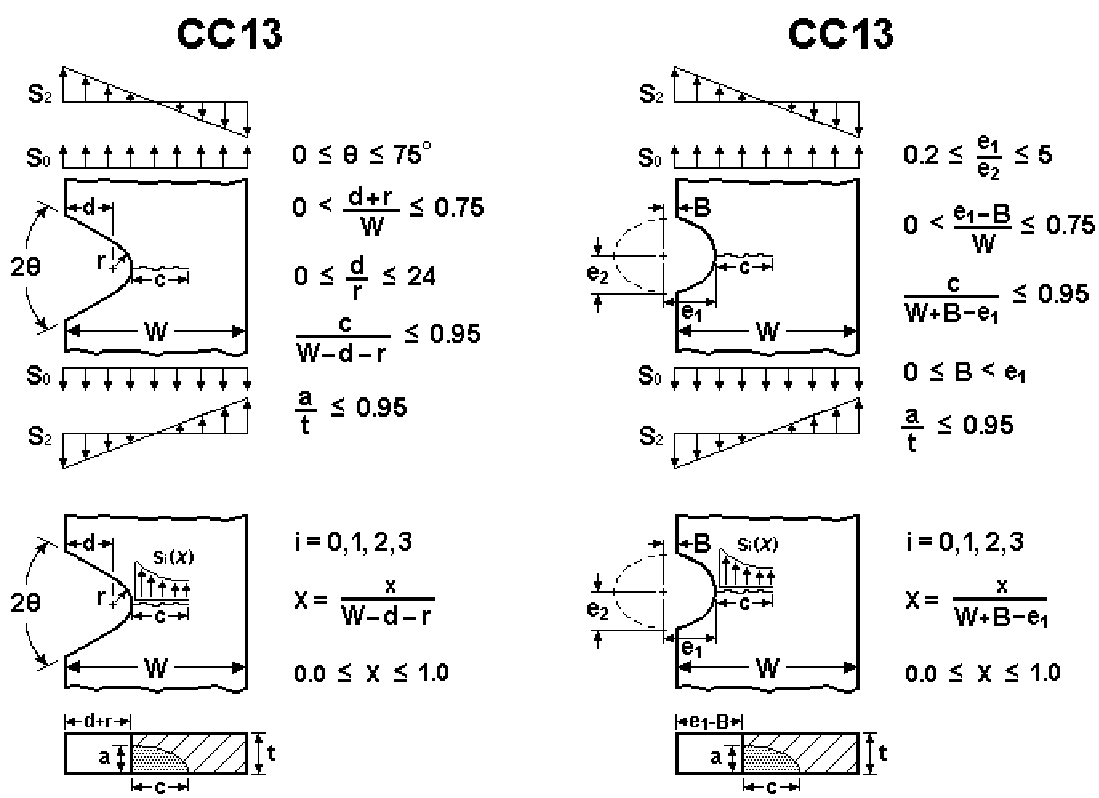


Figure 2.2.39: Corner crack case CC13

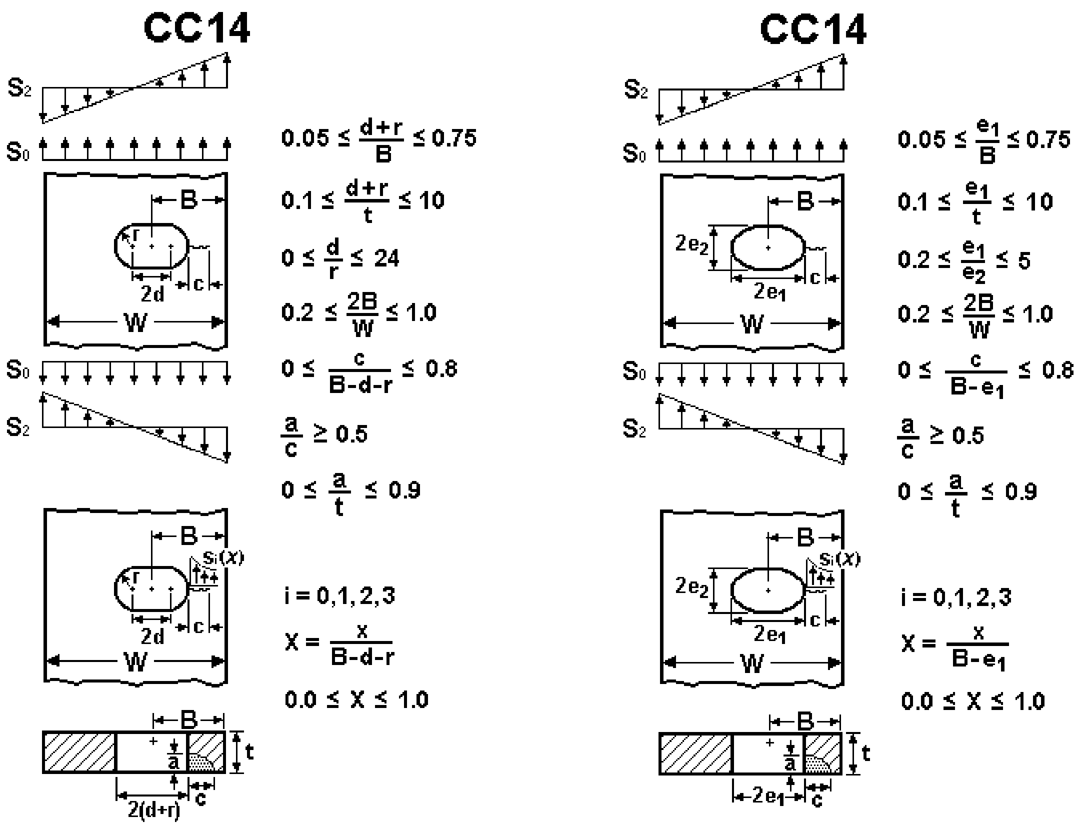


Figure 2.2.40: Corner crack case CC14

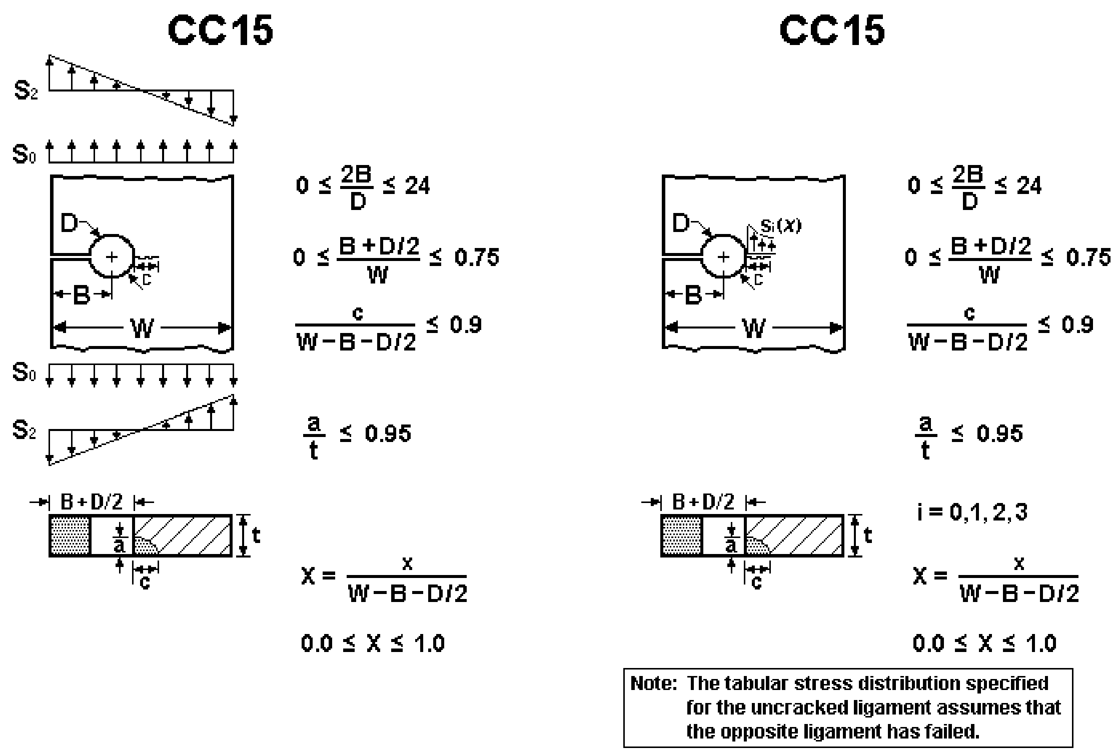


Figure 2.2.41: Corner crack case CC15

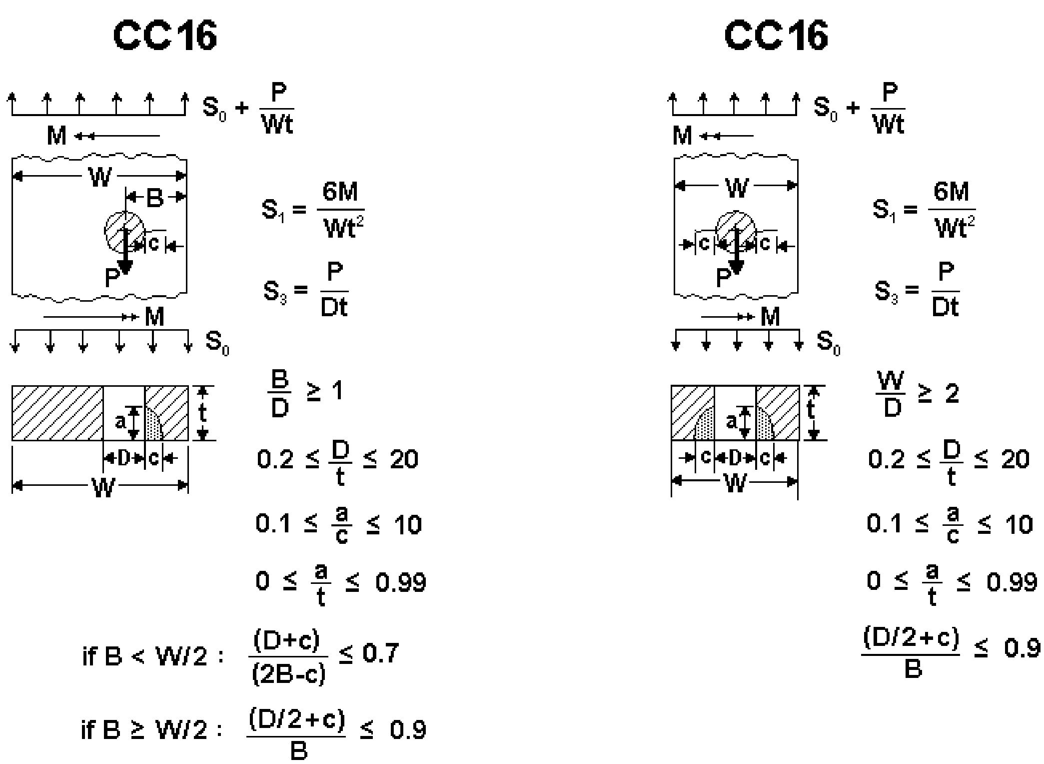


Figure 2.2.42: Corner crack case CC16

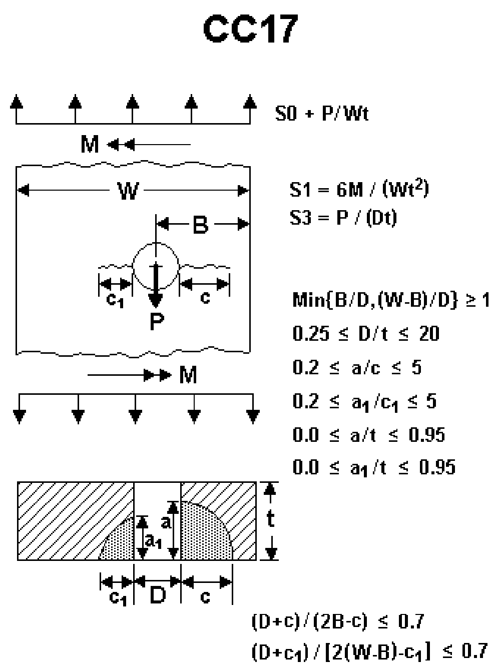


Figure 2.2.43: Corner crack case CC17

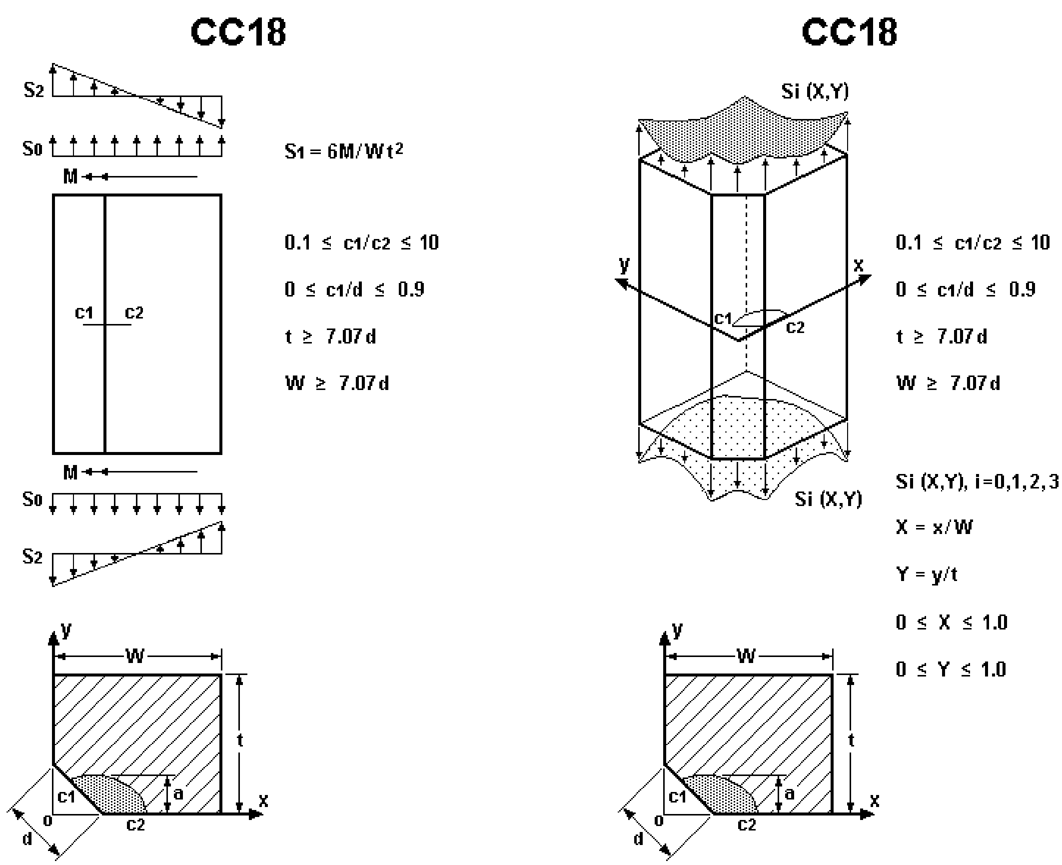


Figure 2.2.44: Corner crack case CC18

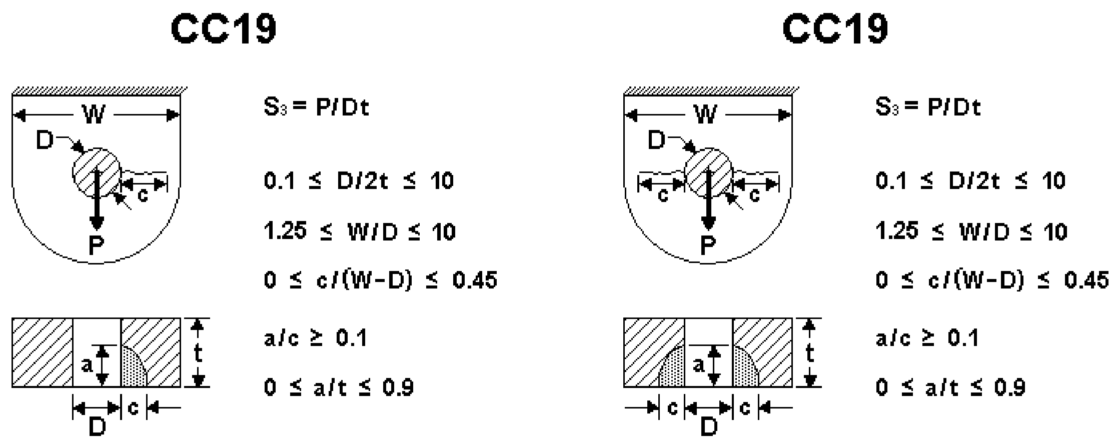


Figure 2.2.45: Corner crack case CC19

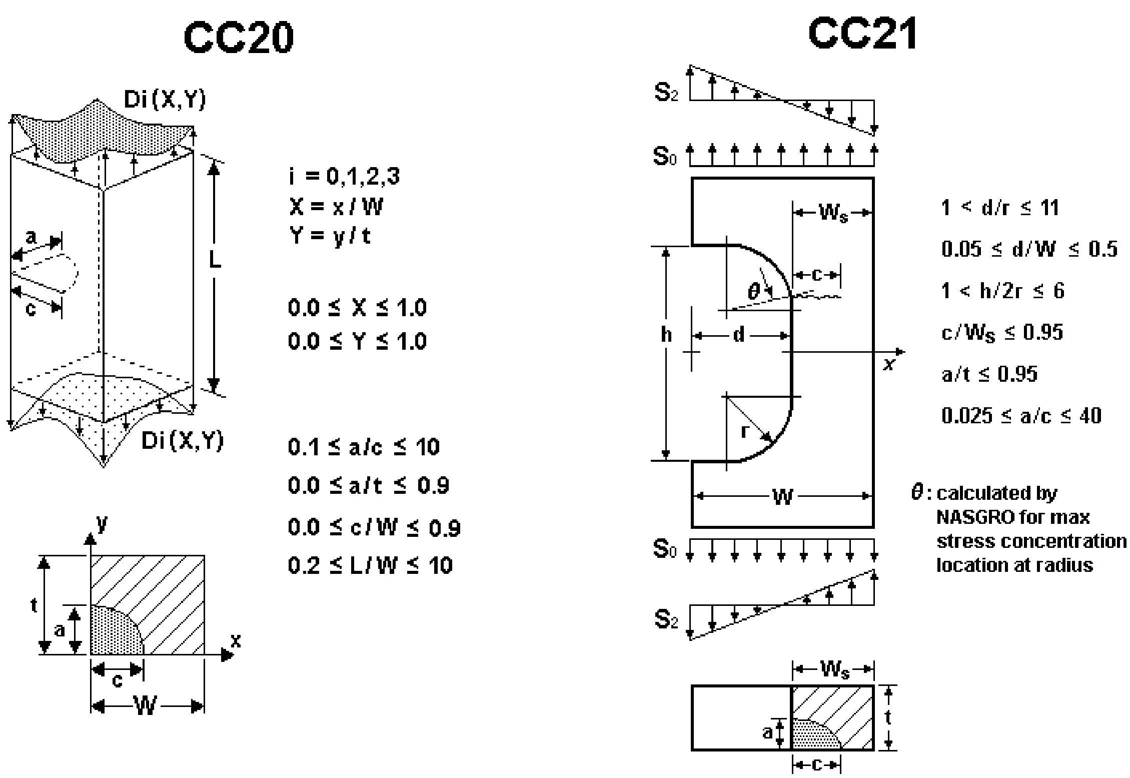


Figure 2.2.46: Corner crack cases CC20 and CC21

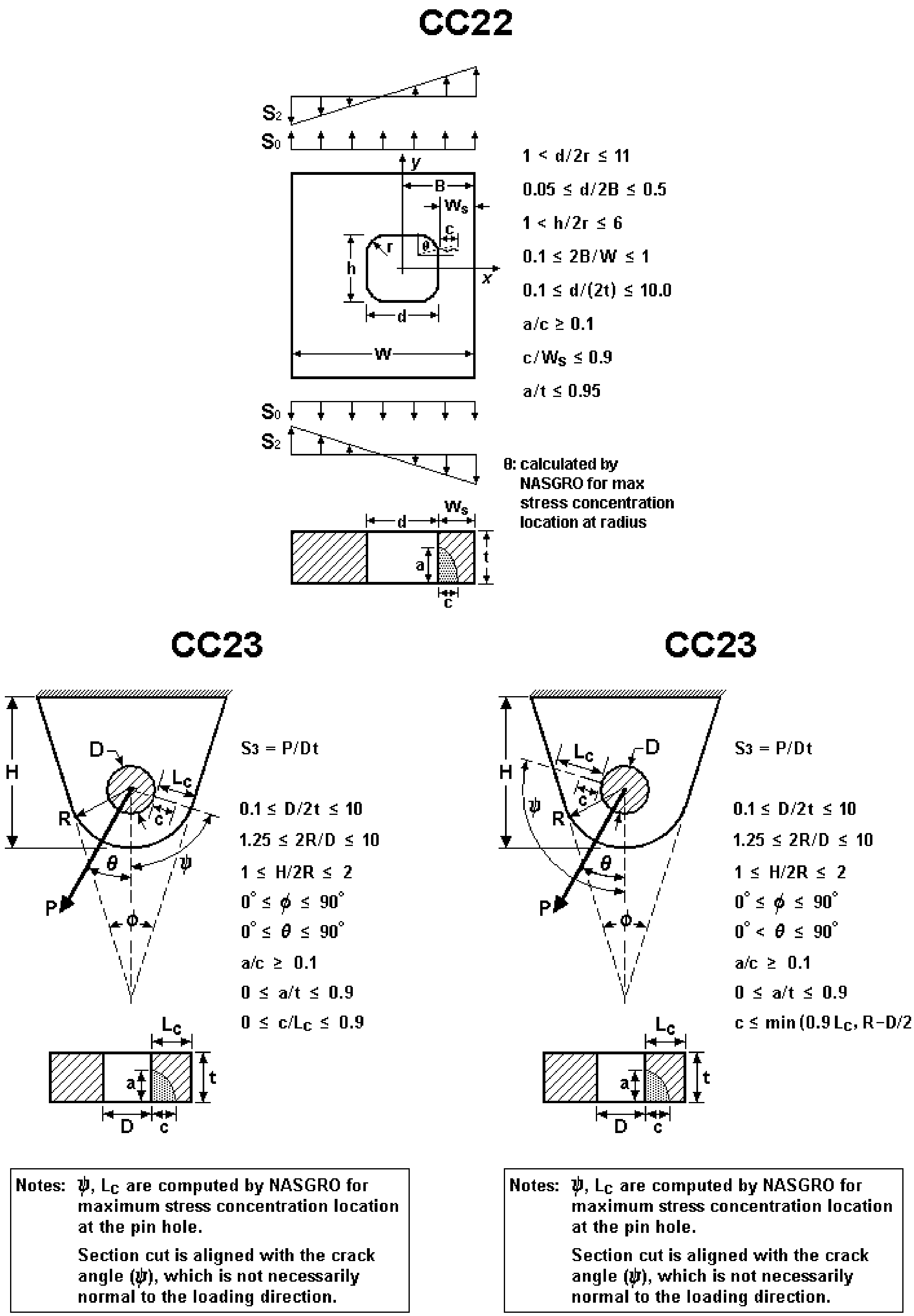


Figure 2.2.47: Corner crack cases CC22 and CC23

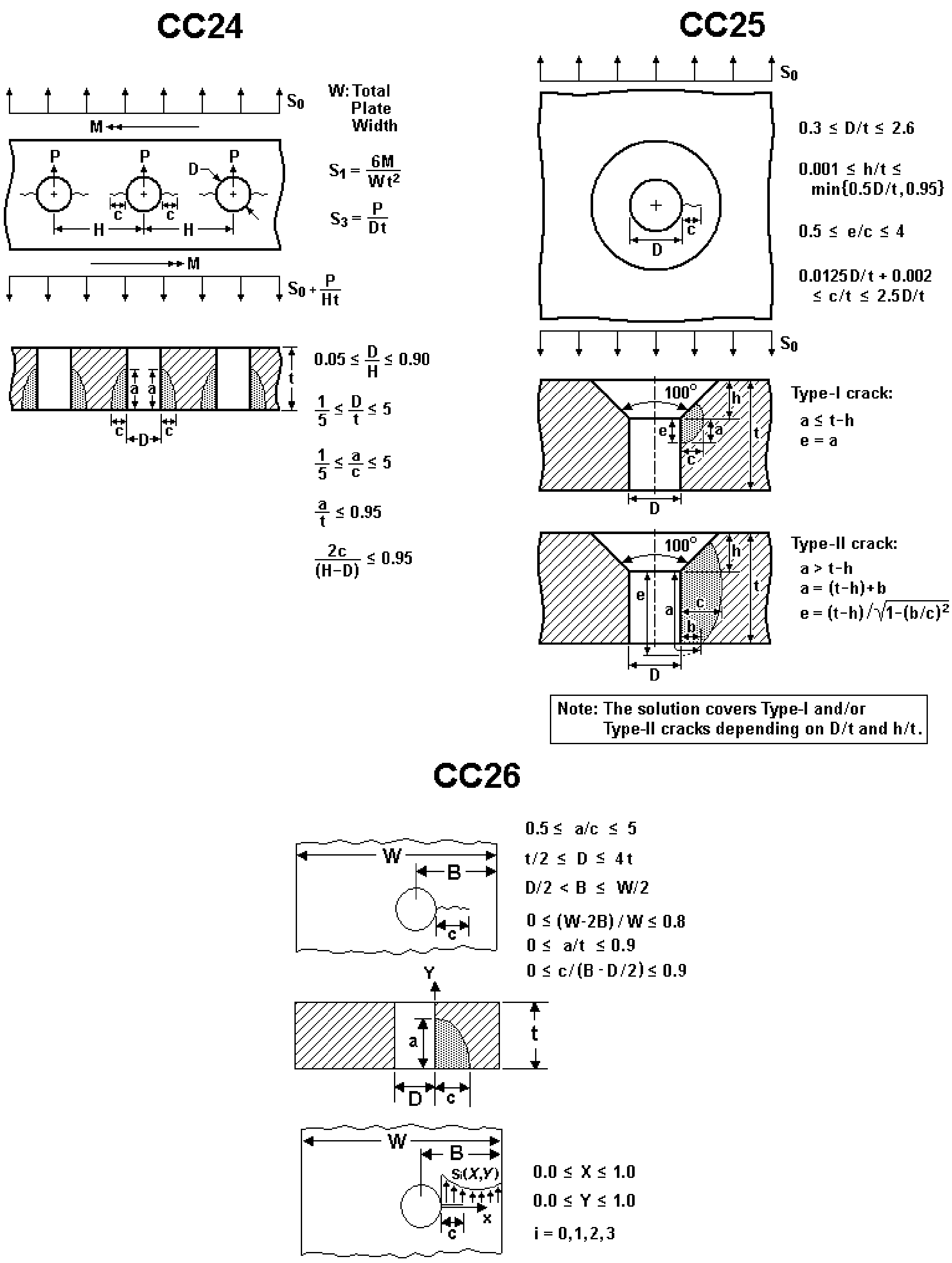


Figure 2.2.48: Corner crack cases CC24, CC25, and CC26

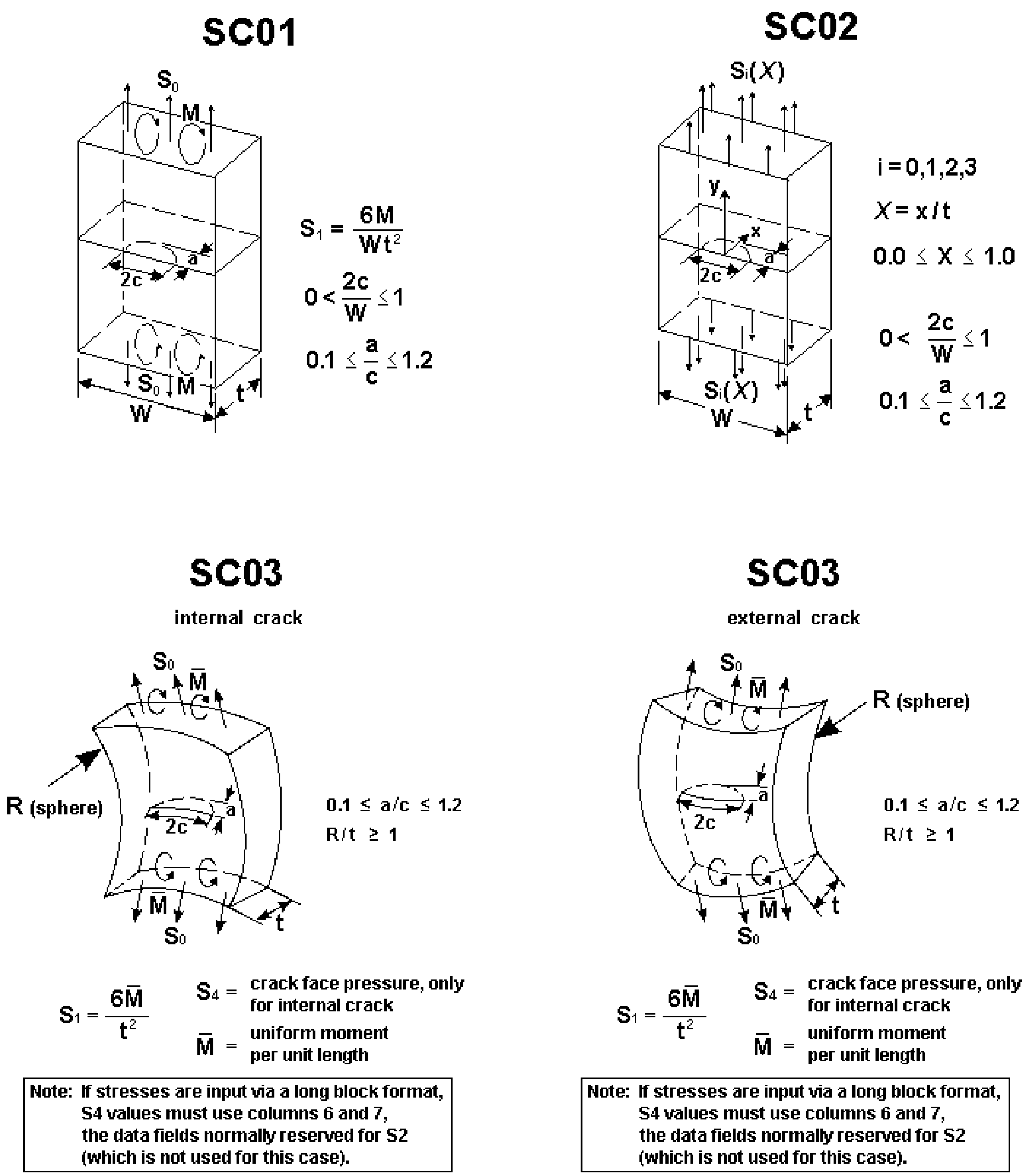


Figure 2.2.49: Surface crack cases SC01, SC02, and SC03

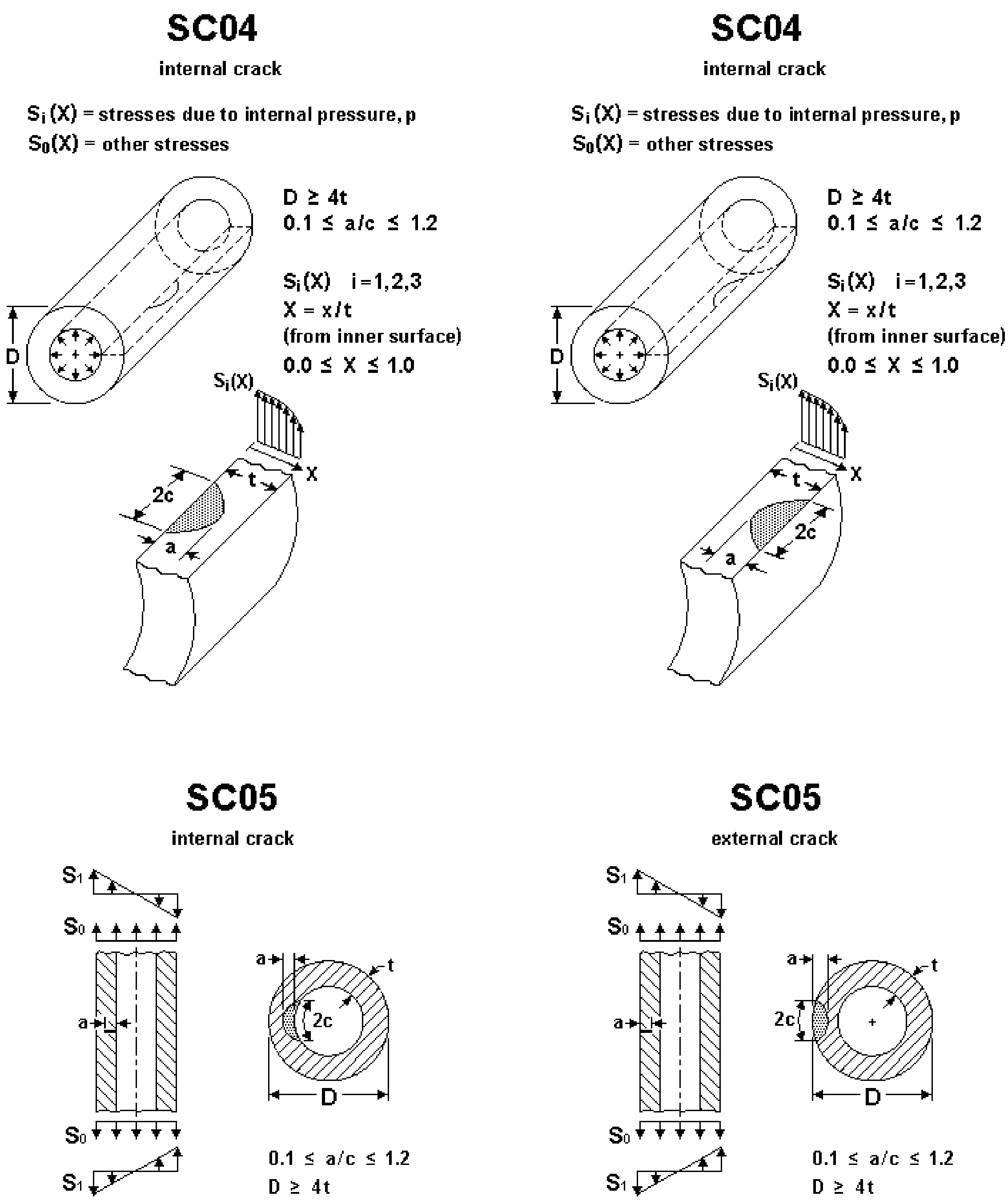


Figure 2.2.50: Surface crack cases SC04 and SC05

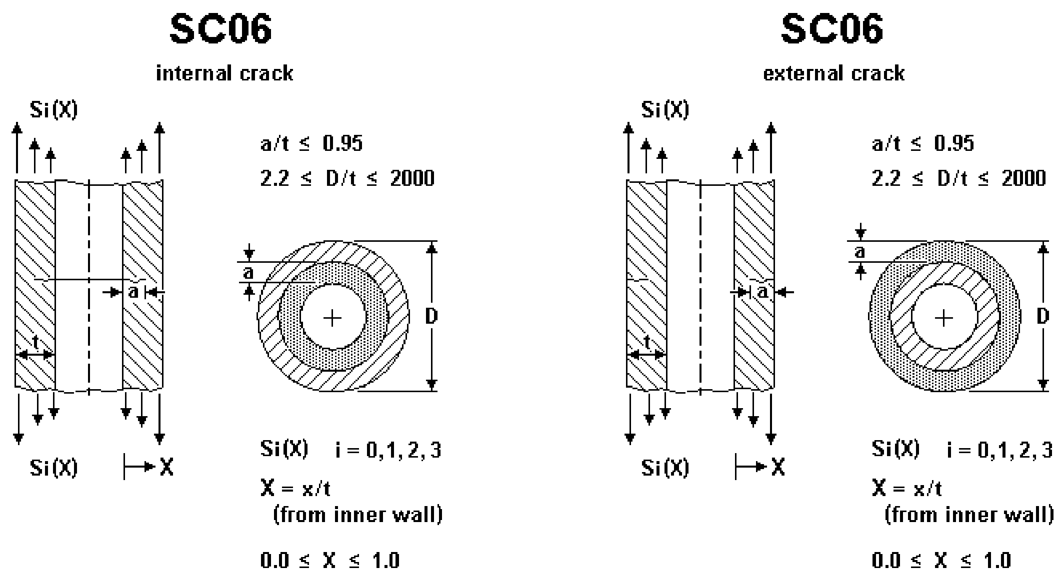


Figure 2.2.51: Surface crack case SC06

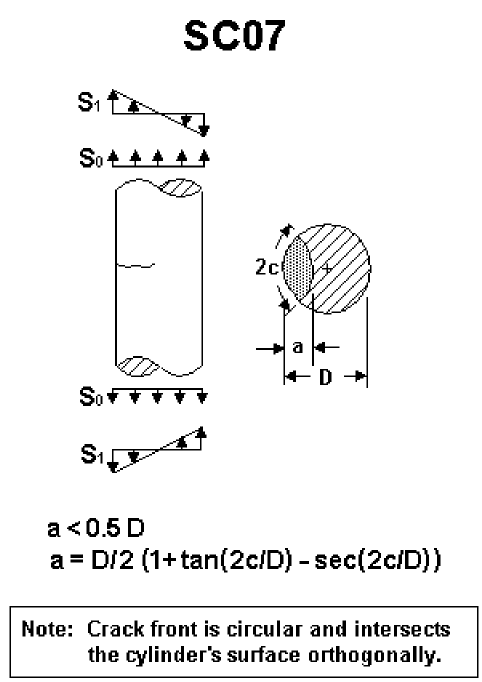


Figure 2.2.52: Surface crack case SC07

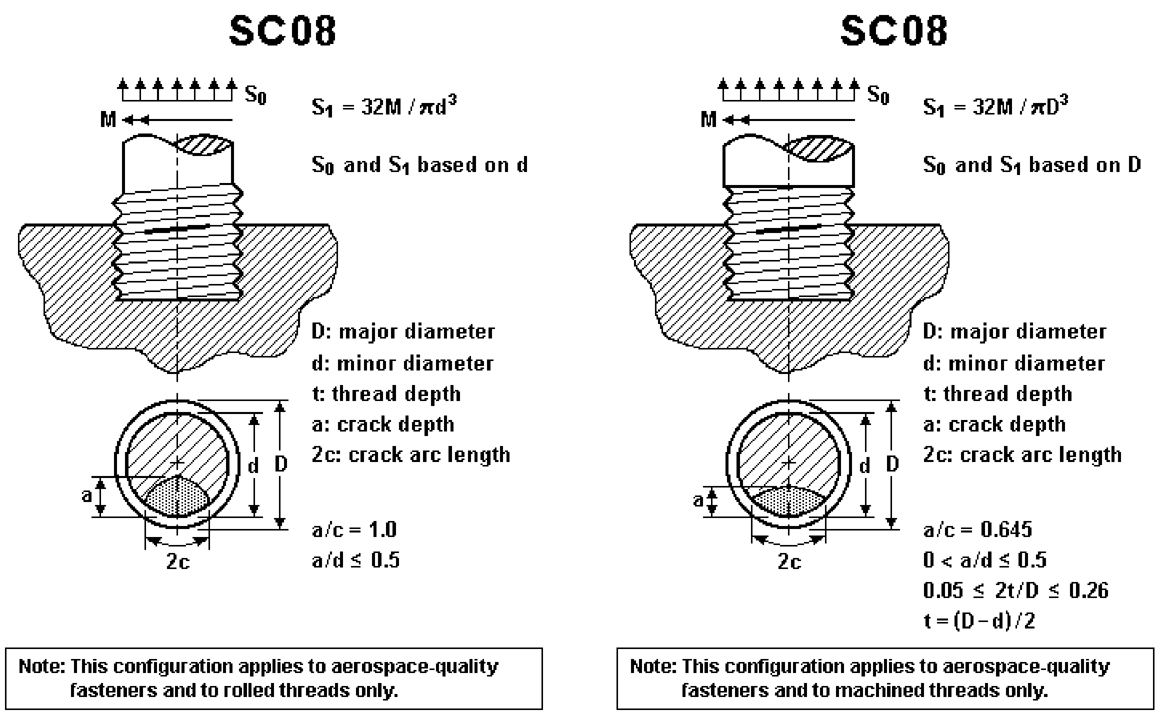


Figure 2.2.53: Surface crack case SC08

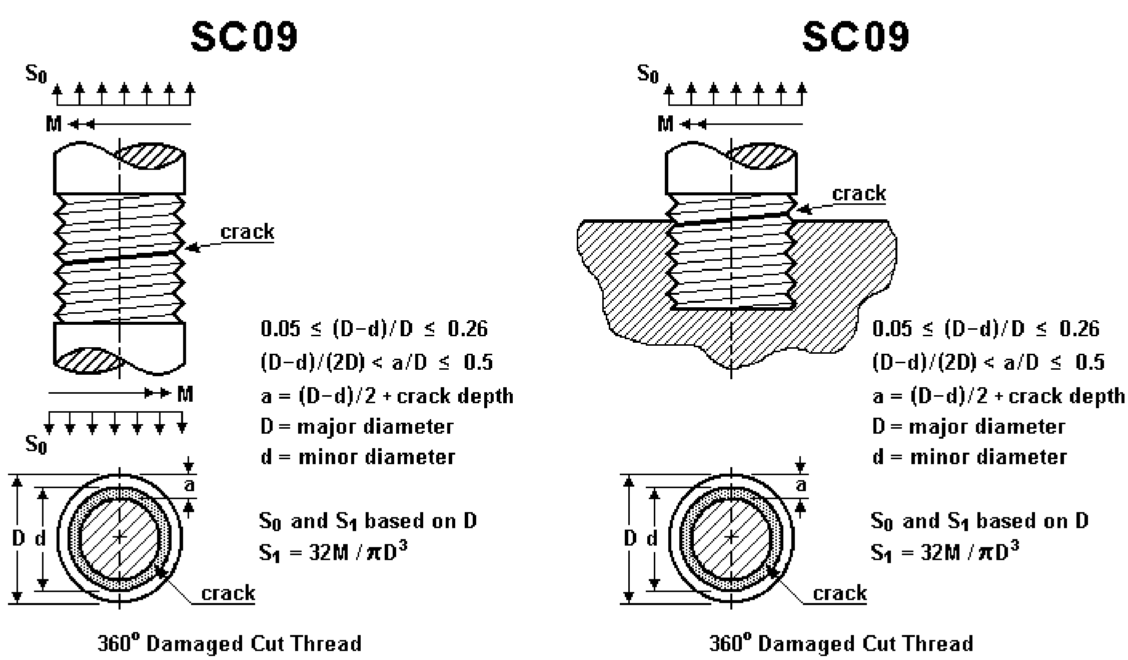


Figure 2.2.54: Surface crack case SC09

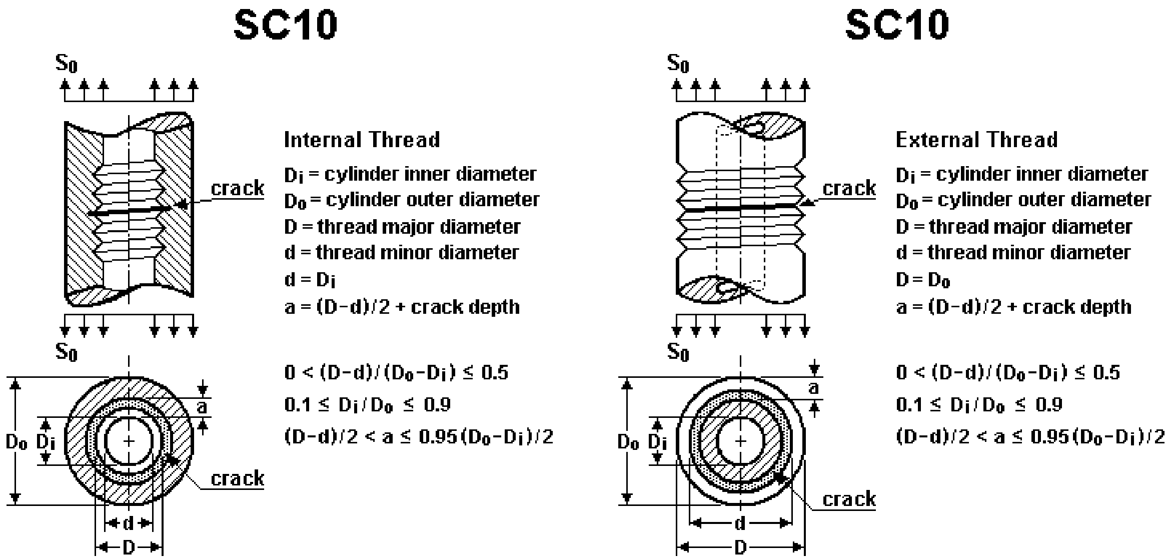


Figure 2.2.55: Surface crack case SC10

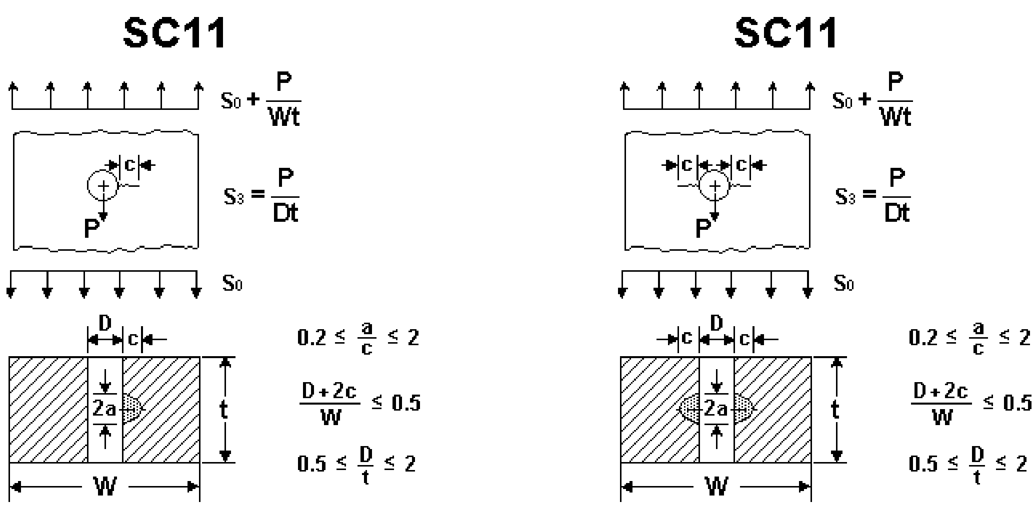


Figure 2.2.56: Surface crack case SC11

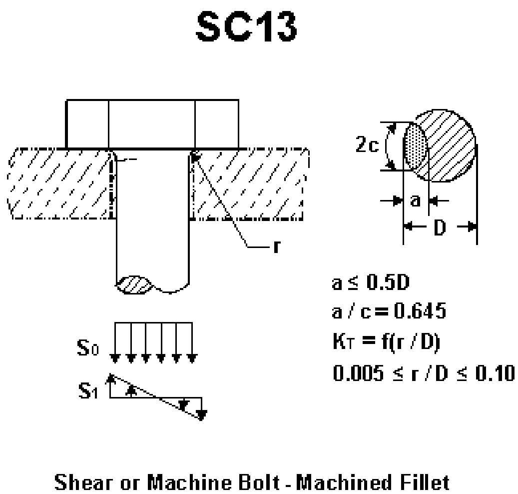


Figure 2.2.57: Surface crack case SC13

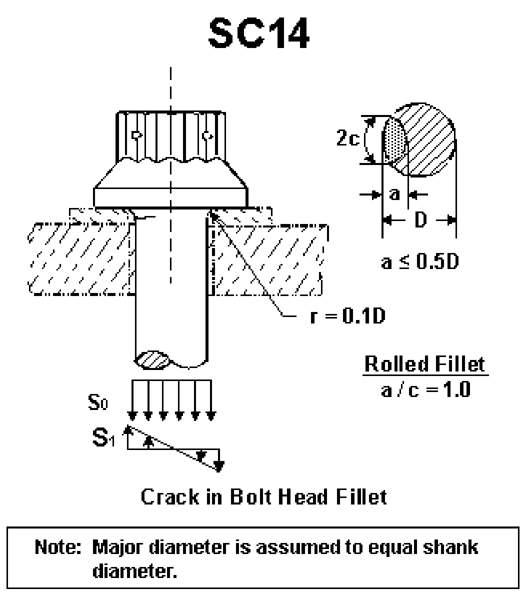


Figure 2.2.58: Surface crack case SC14

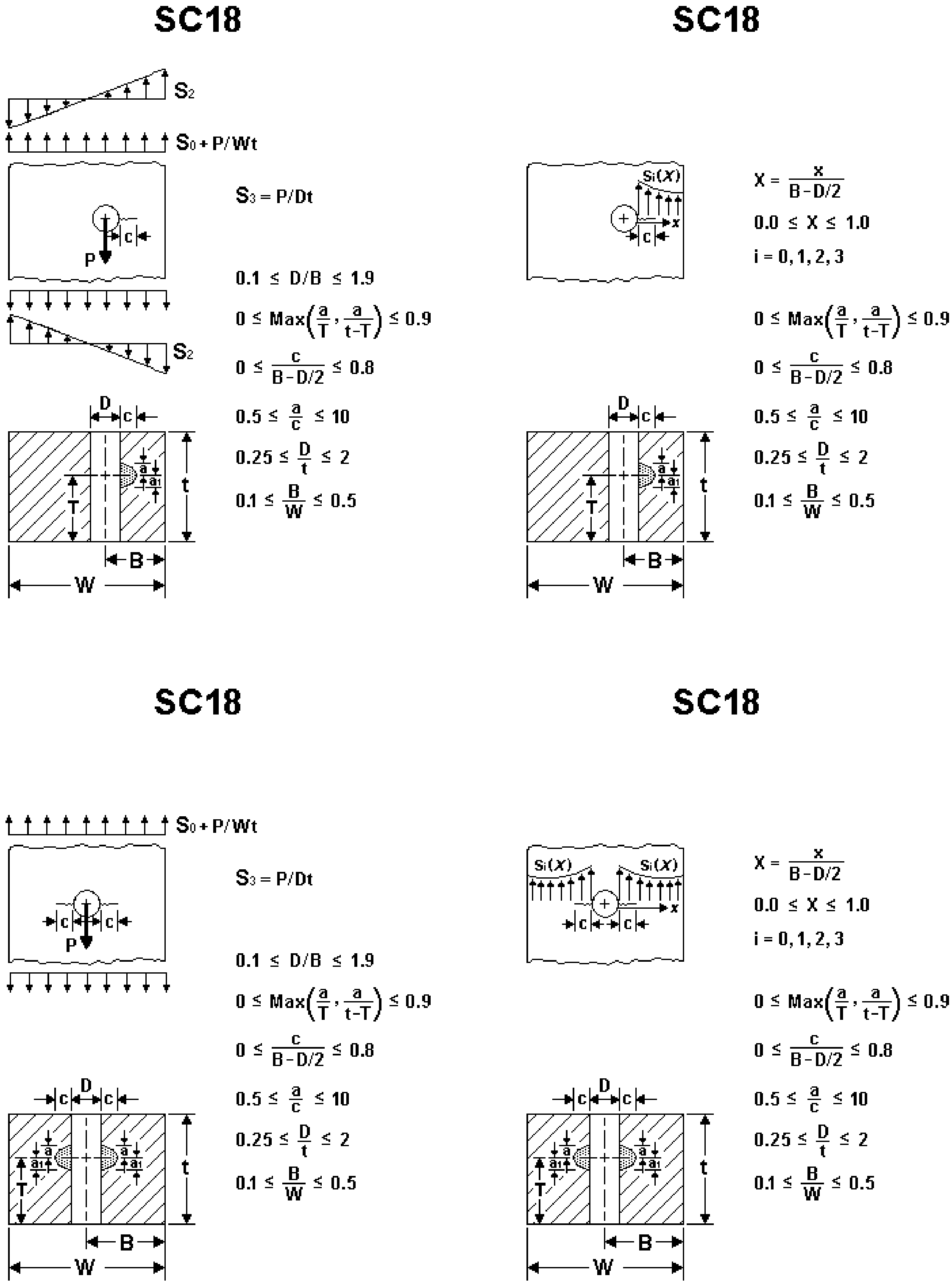


Figure 2.2.59: Surface crack case SC18

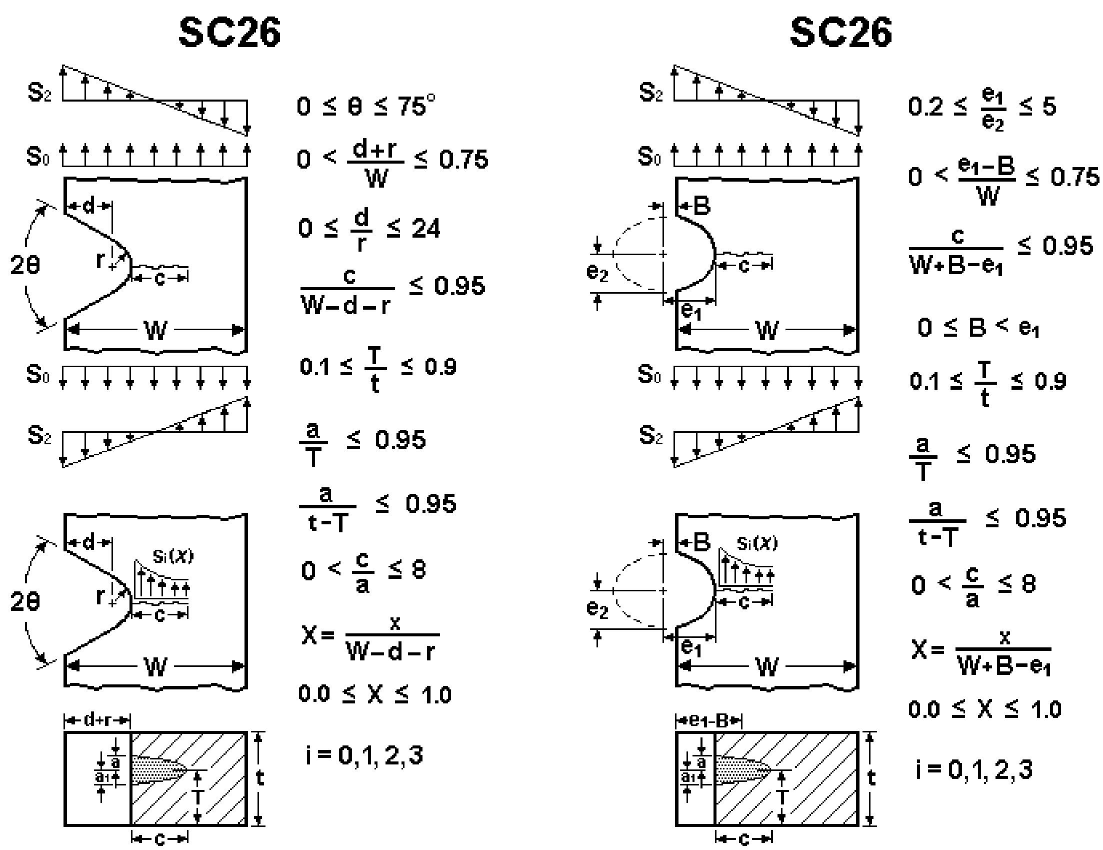


Figure 2.2.60: Surface crack case SC26

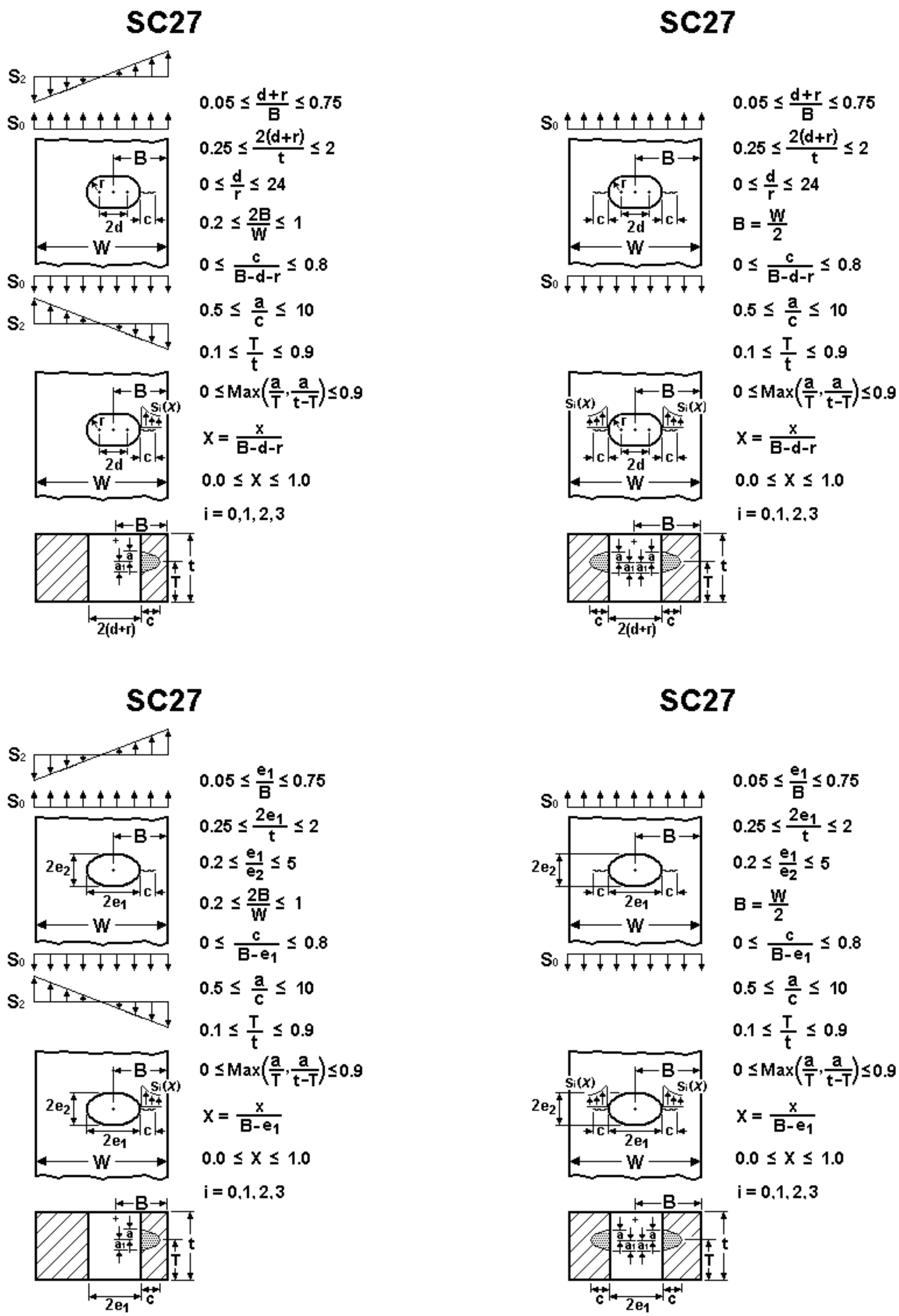


Figure 2.2.61: Surface crack case SC27

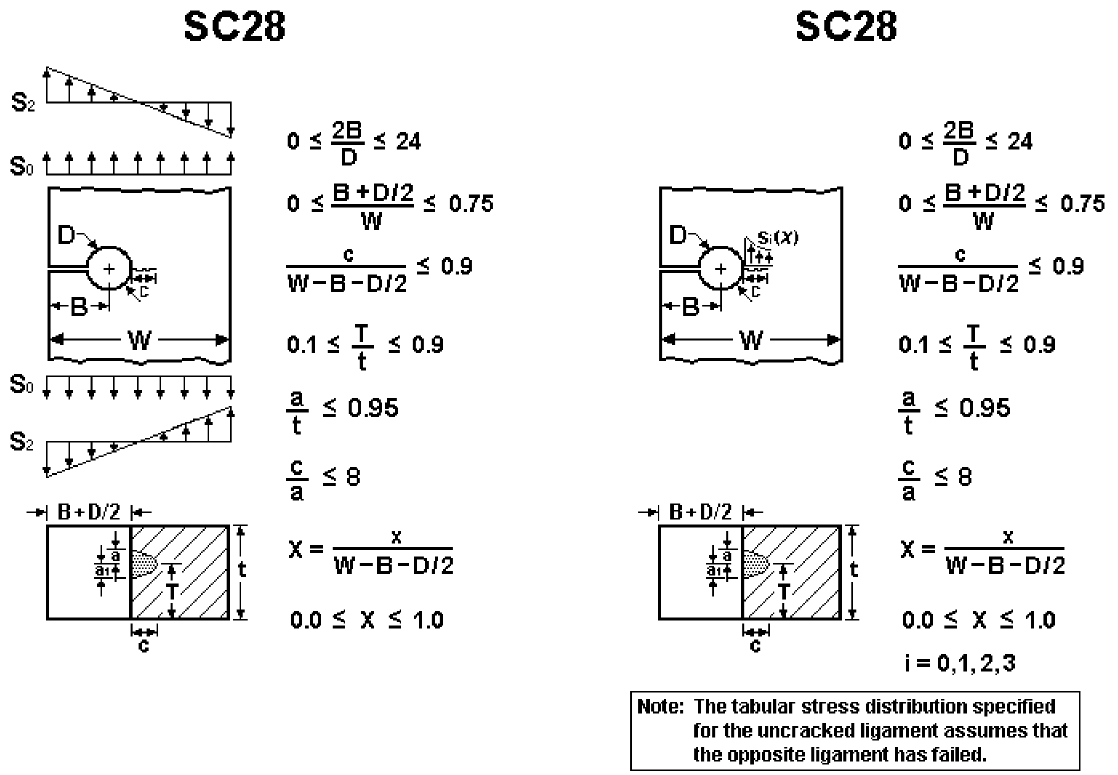


Figure 2.2.62: Surface crack case SC28

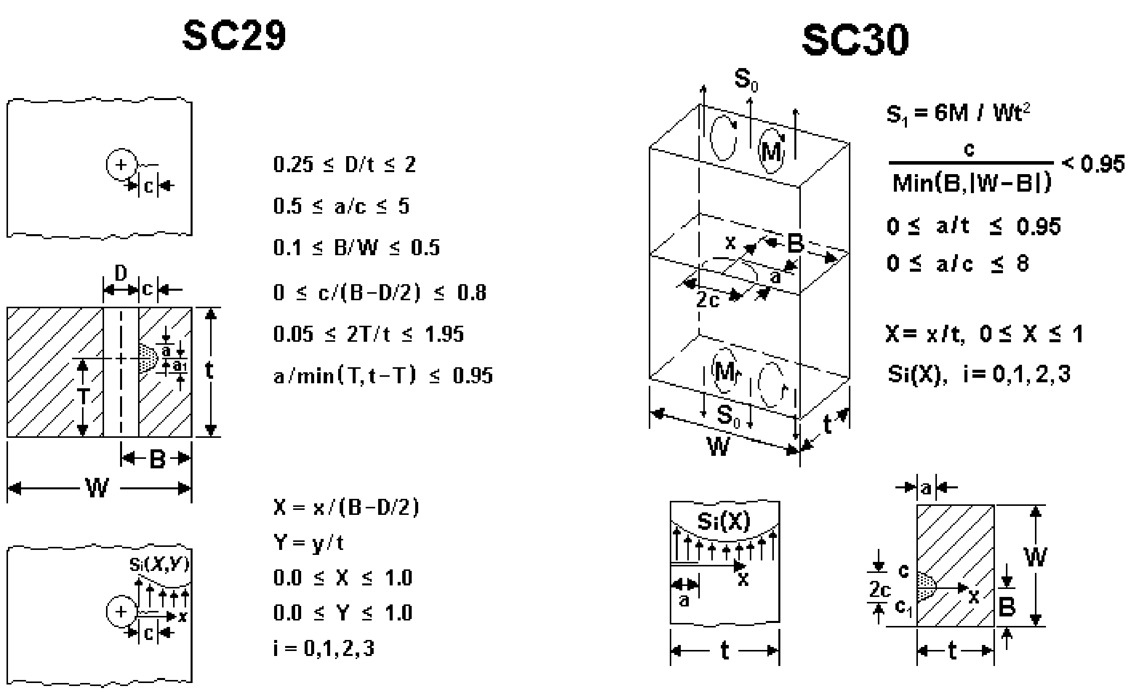


Figure 2.2.63: Surface crack cases SC29 and SC30

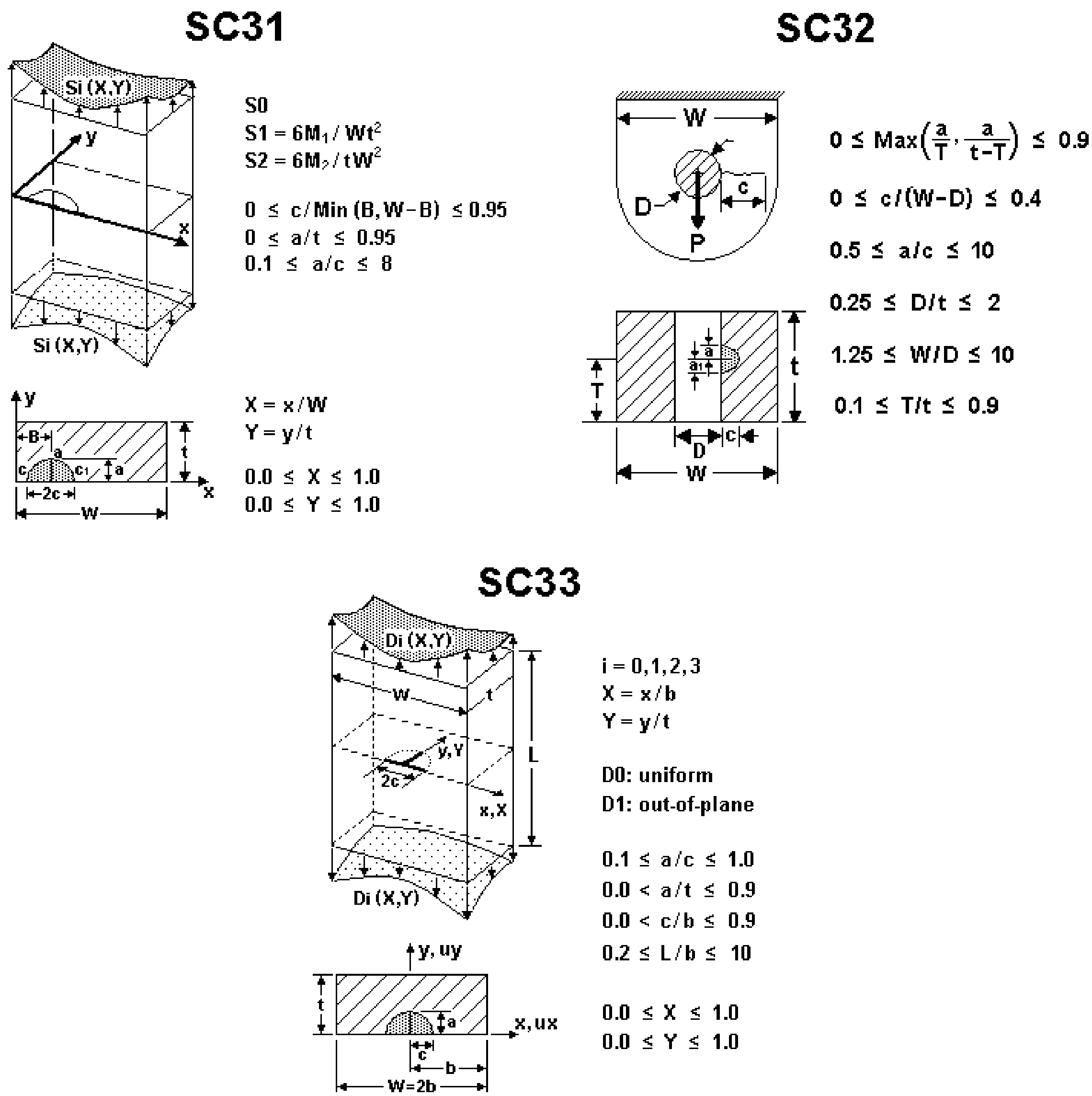


Figure 2.2.64: Surface crack cases SC31, SC32, and SC33

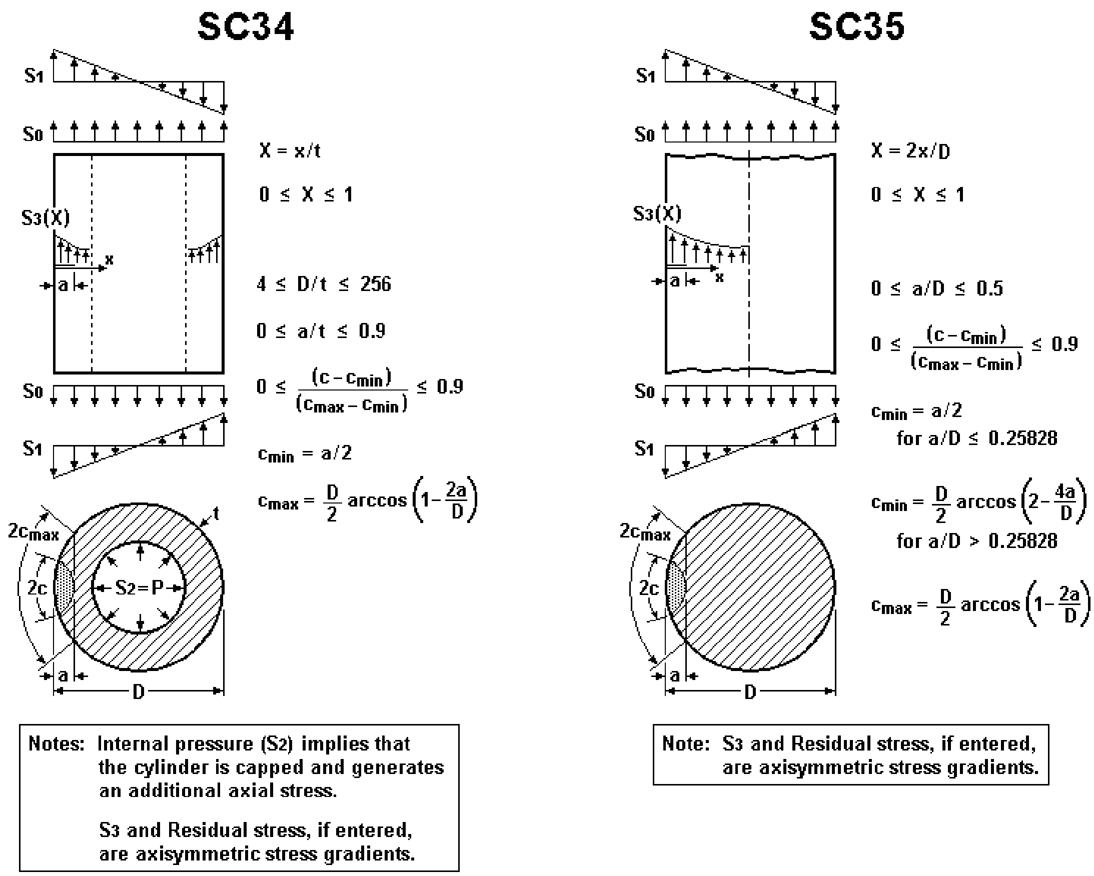


Figure 2.2.65: Surface crack cases SC34 and SC35

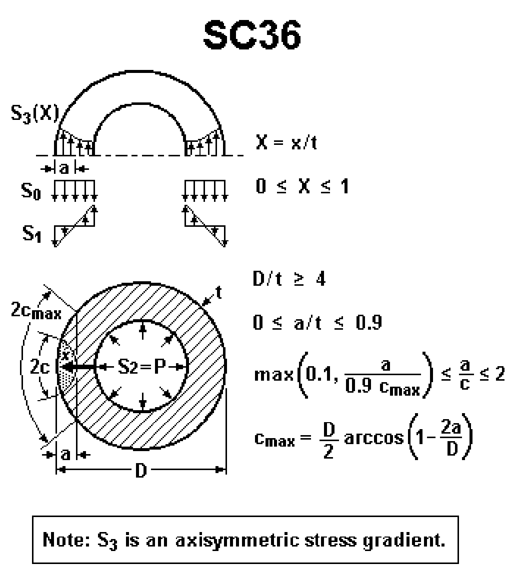


Figure 2.2.66: Surface crack case SC36

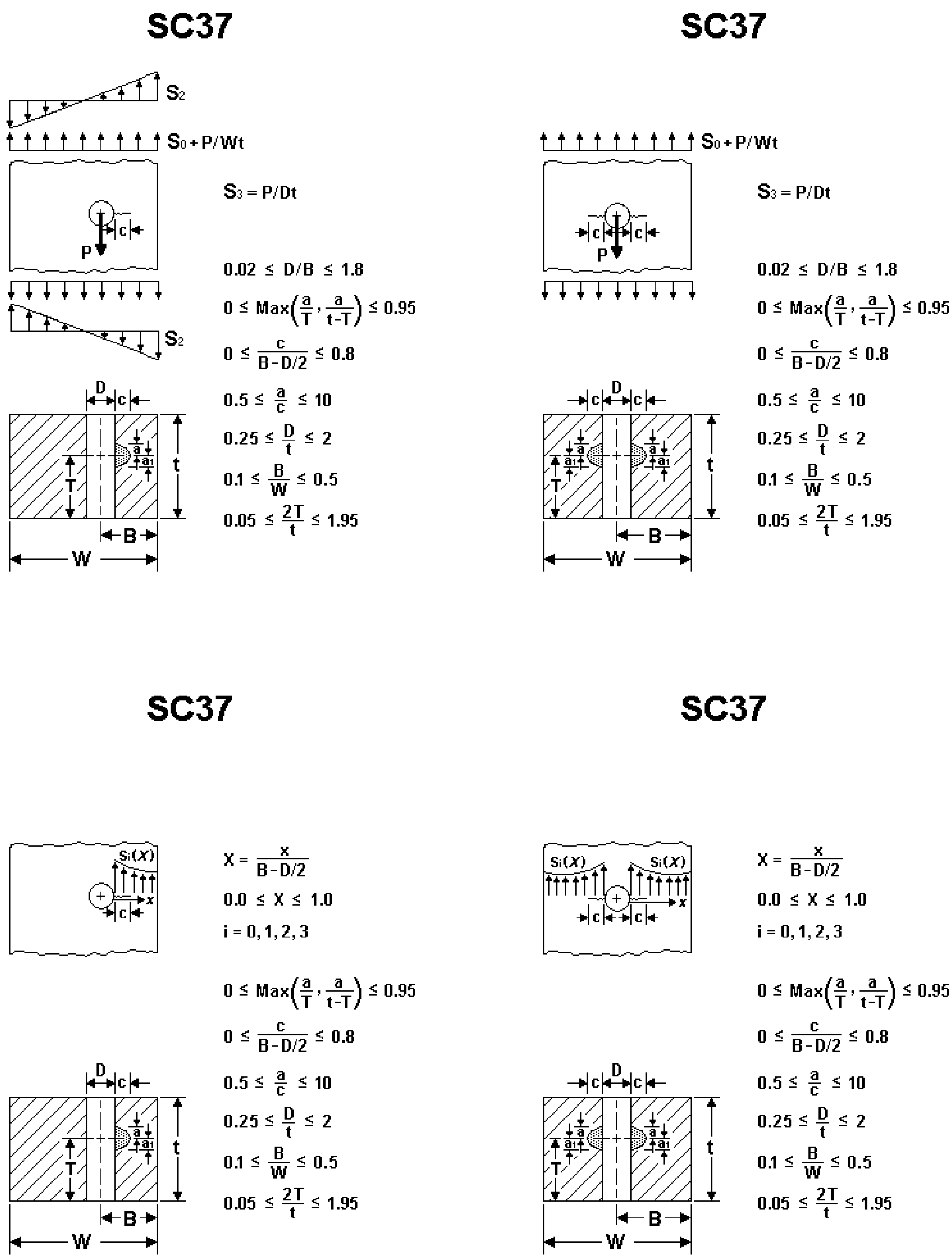


Figure 2.2.67: Surface crack case SC37

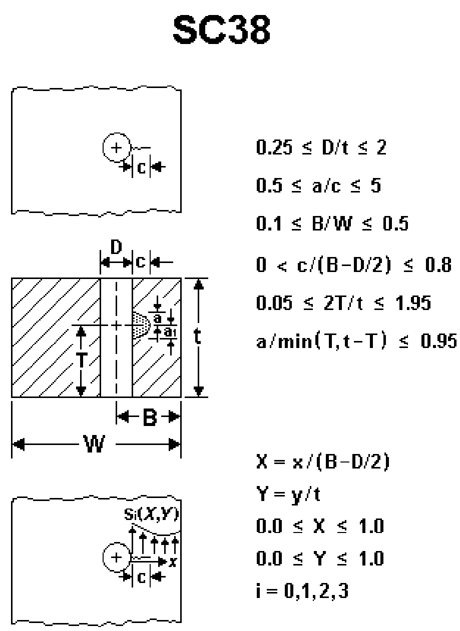


Figure 2.2.68: Surface crack case SC38

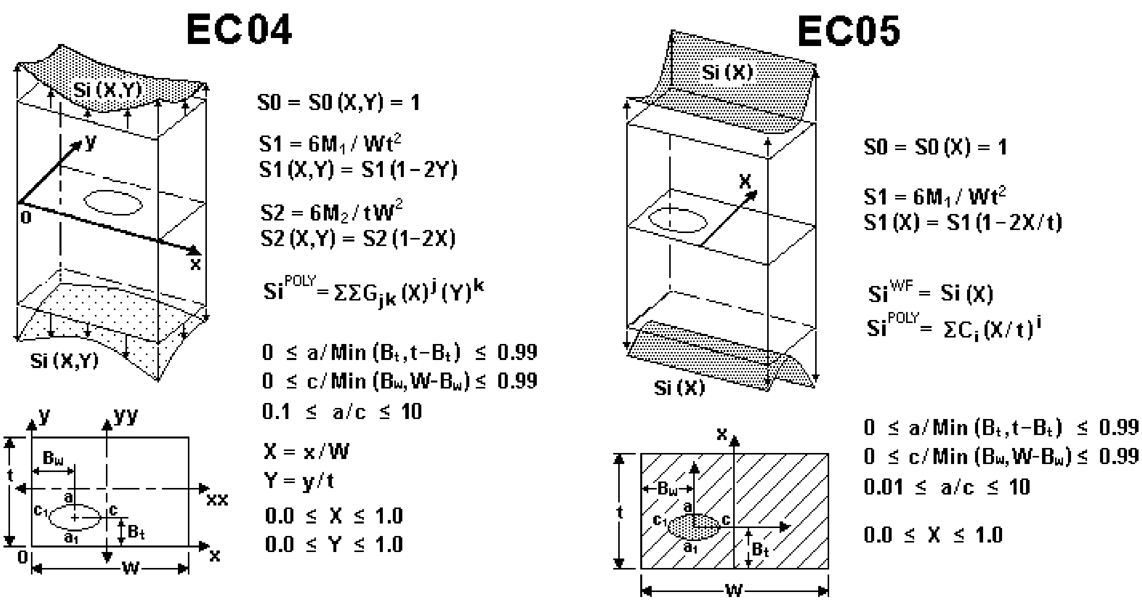


Figure 2.2.69: Embedded crack cases EC04 and EC05

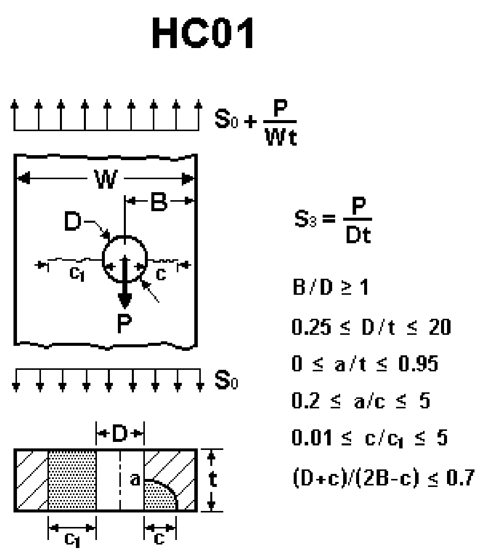


Figure 2.2.70: Hybrid crack case HC01

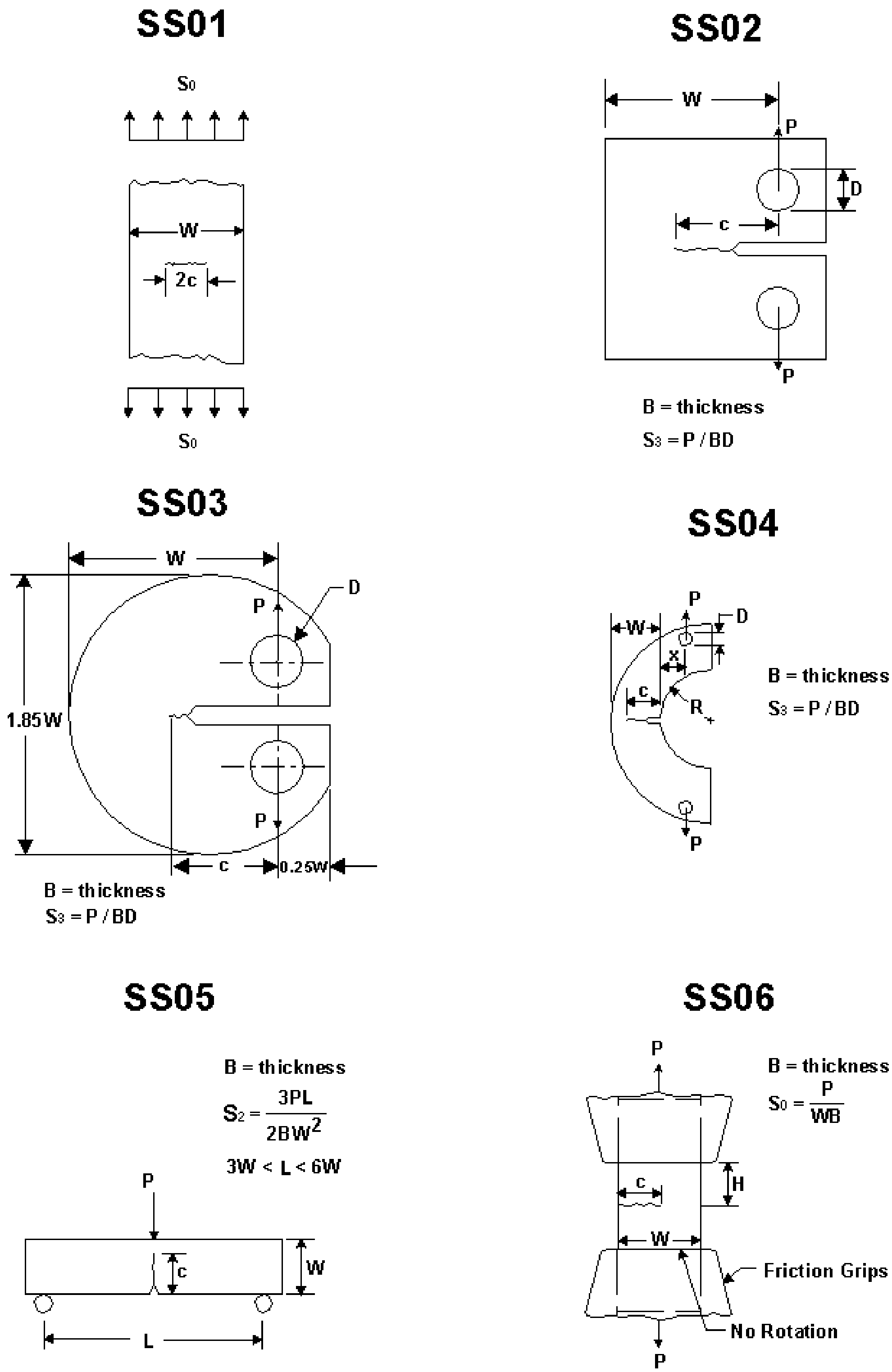


Figure 2.2.71: Standard specimen crack cases SS01, SS02, SS03, SS04, SS05, and SS06

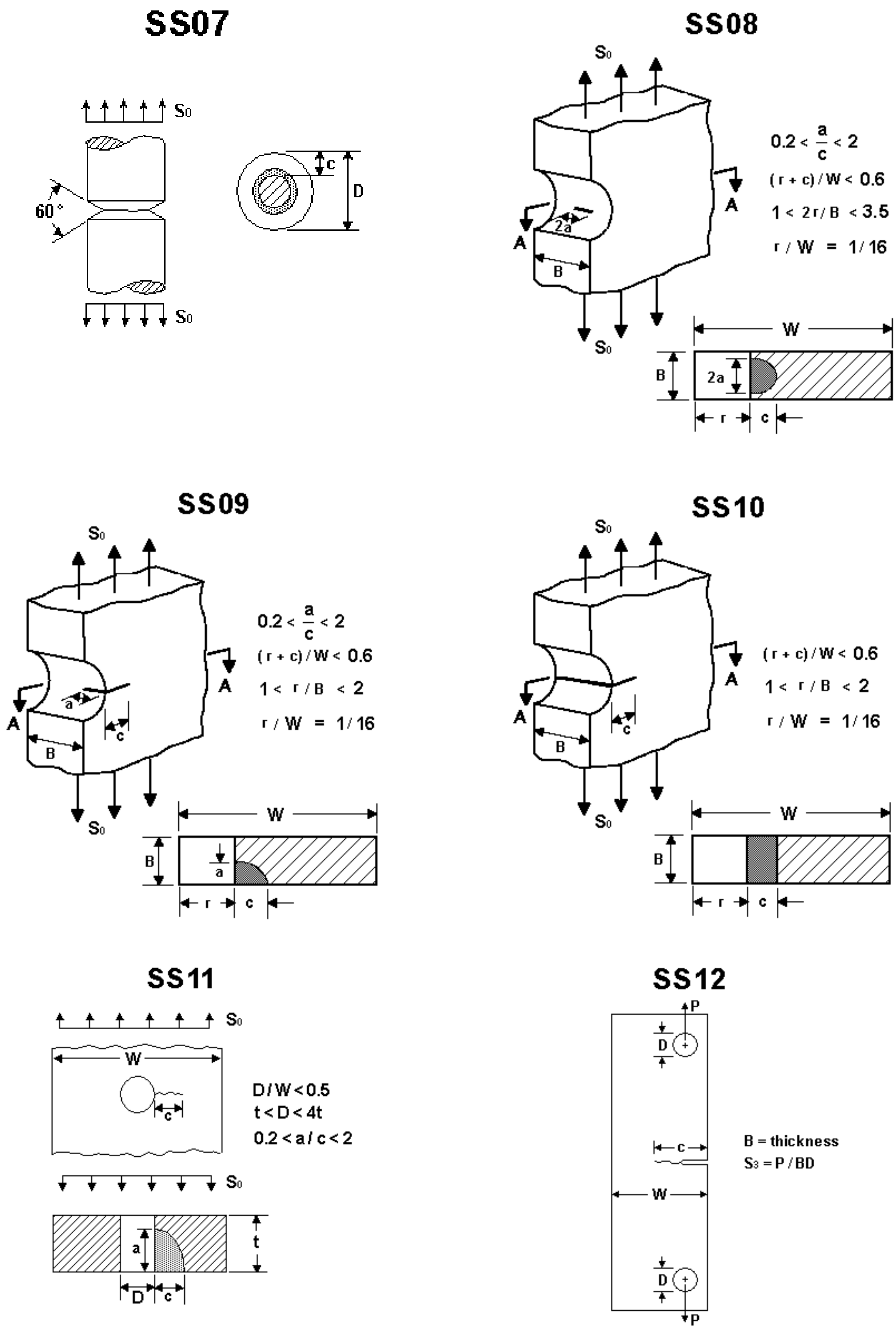


Figure 2.2.72: Standard specimen crack cases SS07, SS08, SS09, SS10, SS11, and SS12

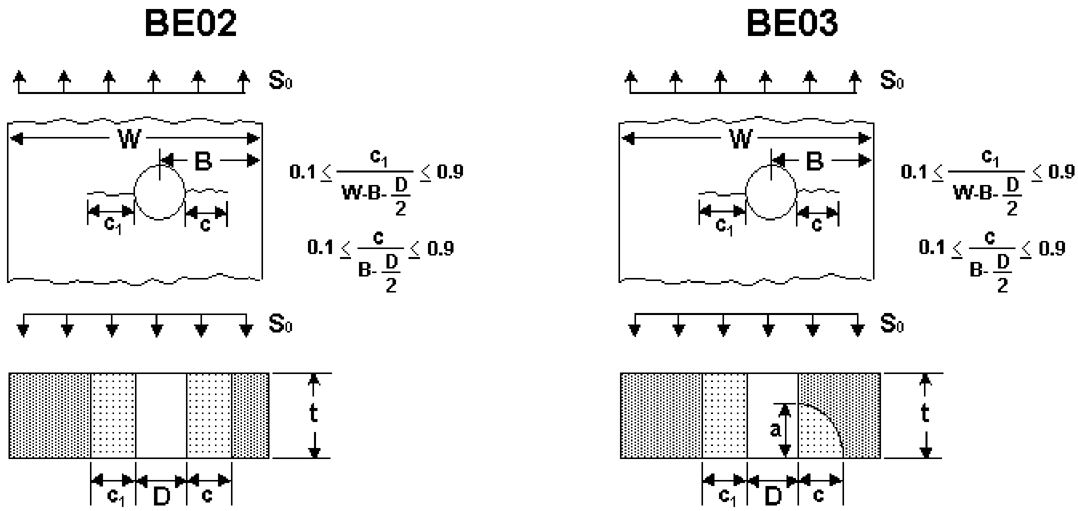


Figure 2.2.73: Boundary element crack cases BE02 and BE03

2.2.5 Entering the Initial Flaw Size

NASGRO offers two options for input of the initial flaw size:

- **User entry**: the user types the flaw size in a text box
- **NASA standard NDE**: the user selects a nondestructive evaluation (NDE) method from a list of NASA-approved methods and the initial flaw size is set automatically according to the chosen method

The NASA standard NDE crack size has a high probability of detection when an inspection is performed in accordance with the proper NASA specifications (as taken from the NASA NDE requirements document). From a damage tolerance point of view, the NASA standard NDE flaw size is one that may be just missed by the inspector and hence the structure should be able to withstand it for certain number of fatigue load cycles.

The current NASA NDE requirements document NASA-STD-5009 ("*Nondestructive Evaluation Requirements for Fracture-Critical Metallic Components*") was published in 2008; this supersedes the prior requirements document, MSFC-STD-1249 ("*Standard NDE Guidelines and Requirements for Fracture Control Programs*"). The requirements document establishes the NDE specifications (including inspector qualifications, applicable methods and initial flaw sizes) for any NASA system or component, flight or ground, where fracture control is a requirement.

As of v6.0 (released 3/2009), NASGRO's list of NASA standard NDE initial flaw sizes and methods reflects the contents of NASA-STD-5009. The essential differences between v6.0 (NASA-STD-5009) and v5.22 (MSFC-STD-1249) in terms of NASGRO crack cases are shown in Tables 2.2.3 and 2.2.4 for US customary and SI units, respectively.

NASGRO offers information from the NASA NDE requirements as a courtesy to users. These flaw sizes may or may not be applicable to other industries or organizations. No warranty is made to the completeness or applicability of the NASGRO list to any specific application. Users are encouraged to verify the applicability of this information to their specific hardware:

- NASA users: consult your appropriate Fracture Control authority