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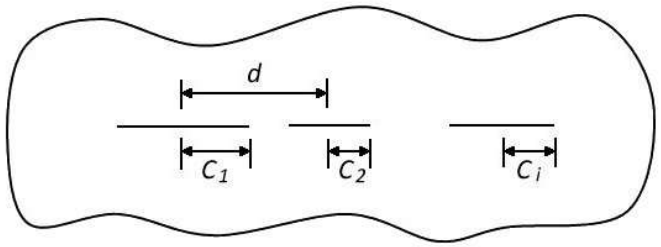
AFGROW Workshop 2022

Multisite Damage Solution

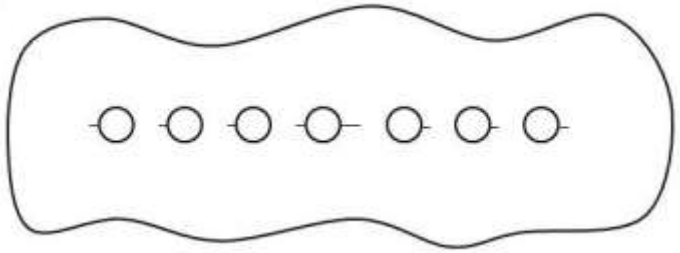
James Harter, Alexander Litvinov

LexTech, Inc .

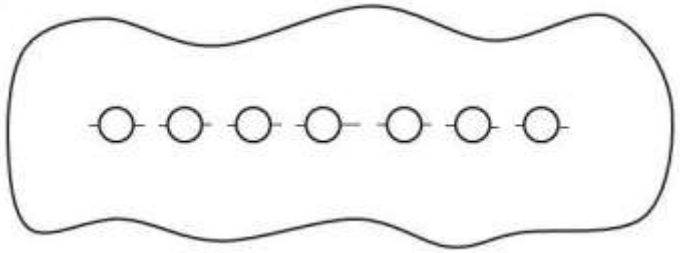
Through Crack Cases
(Infinite Plate)



Multiple Through Cracks



Multiple Holes, Continuing Damage



Multiple Holes, Full MSD Scenario

Baseline Reference

AFRL-RQ-WP-TR-2014-0233

IMPROVED STRESS INTENSITY SOLUTIONS DEVELOPED FOR THE MULTIPLE SITE DAMAGE SCENARIO

Two Unequal Through Cracks on Either Side of an Open Hole, Multiple Through Cracks, and Through Cracks Approaching an Open Hole

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OCTOBER 2014
Interim Report

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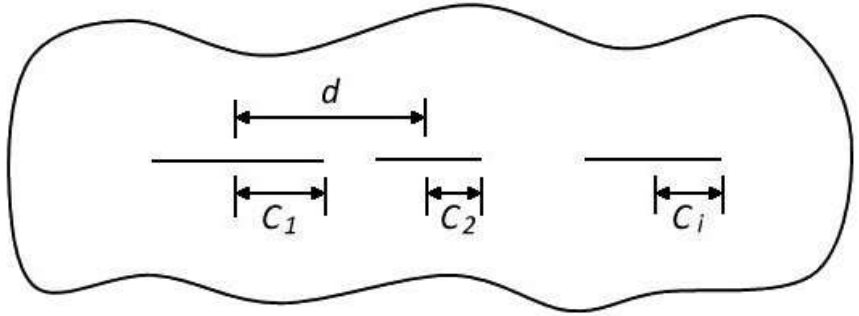
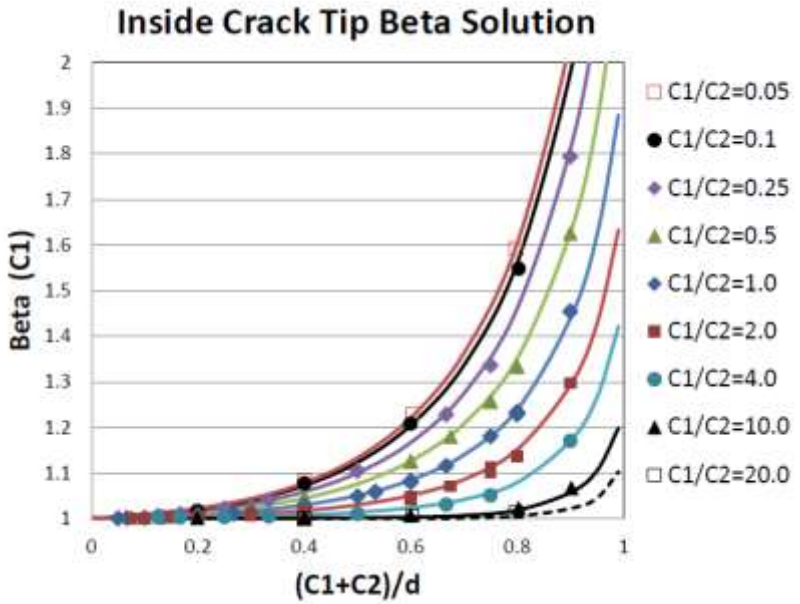
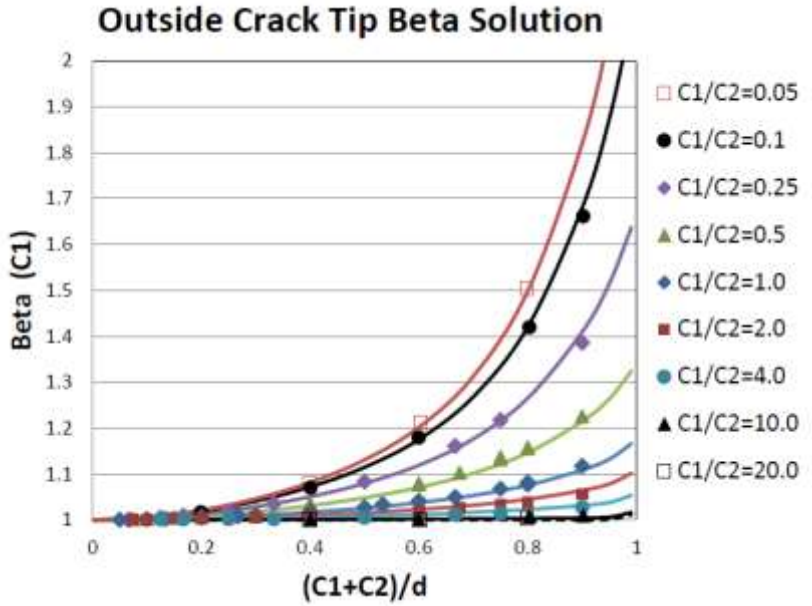
Multiple Through Crack Case

First, consider the two-crack case

Four crack tips (2 inside crack tips and 2 outside crack tips)
Two Parameters: C1/C2, and (C1 + C2)/d



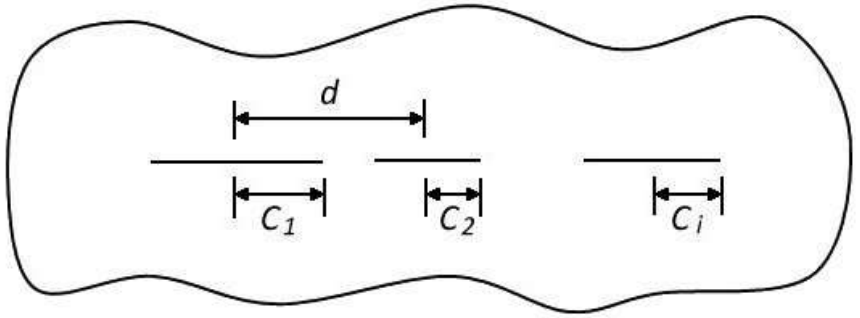




Curve fit solutions available in the baseline reference

Multiple Through Crack Case
Solution Procedure

- To solve for any number of through cracks, consider the crack of interest to be C_1 and calculate the beta value for each crack tip using the appropriate curve fit equation for each crack from 2 through i (total number of cracks).
- The inside crack tip is toward the adjacent crack and the outside crack tip is on the opposite side of the adjacent crack.
- AFGROW will allow 3 <= i <= 9 since the two-crack solution is available in the Advanced Interface
- The method of compounding is used to calculate the final beta solution for each crack tip. $Beta_{total} = Beta_1 * Beta_2 * \ldots * Beta_{(i-1)}$



The curve fit solution is very good for each compounded case, but since the error is also compounded, it can increase somewhat as the number of cracks increase. However, this is mitigated since the distance between cracks also increases so that the solution for several compounded cases will eventually converge toward 1.0. Typical error will be < 3%

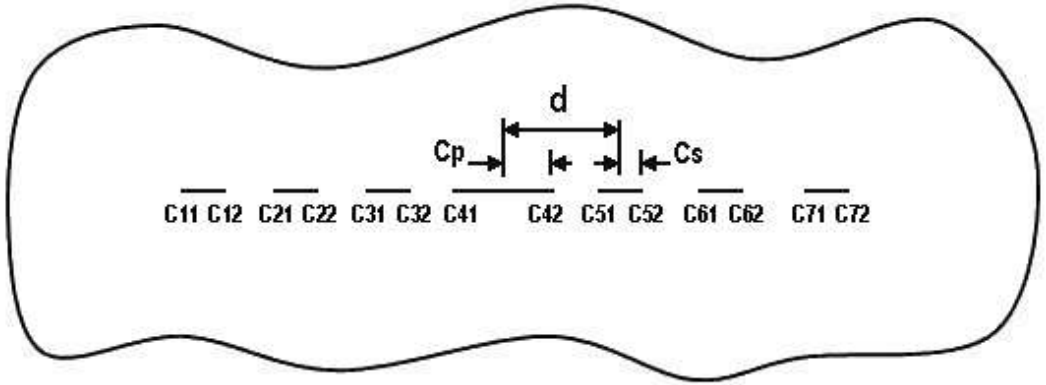
Multiple Through Crack Case
FEM Validation

Width	Spacing	Cp	Cs
75	0.5	0.1	0.05

	K	Beta	Eqn Beta	% Diff
C11	0.3991	1.006982	1.01012	0.3116
C12	0.3998	1.008748	1.02192	1.3057
C21	0.4027	1.016065	1.02043	0.4296
C22	0.4029	1.01657	1.02781	1.1057
C31	0.4074	1.027924	1.03343	0.5356
C32	0.4088	1.031457	1.03941	0.7711
C41	0.5687	1.014631	1.02394	0.9174
C42	0.5687	1.014631	1.02394	0.9174
C51	0.4088	1.031457	1.03941	0.7711
C52	0.4074	1.027924	1.03343	0.5356
C61	0.4029	1.01657	1.02781	1.1057
C62	0.4027	1.016065	1.02043	0.4296
C71	0.3998	1.008748	1.02192	1.3057
C72	0.3991	1.006982	1.01012	0.3116

Width	Spacing	Cp	Cs
150	1	0.1	0.05

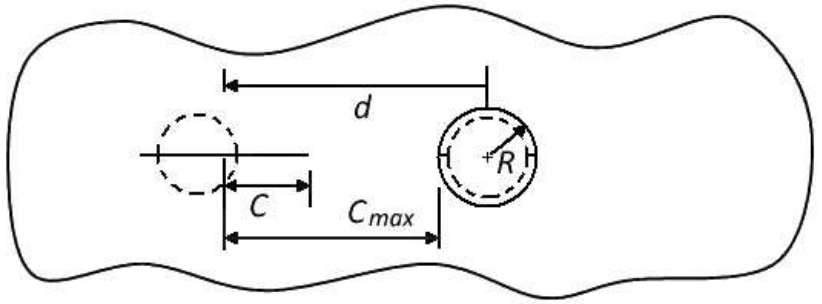
K	Beta	Eqn Beta	% Diff
0.3963	0.999917	1.00336	0.3443
0.3965	1.000422	1.00993	0.9504
0.3978	1.003702	1.00735	0.3634
0.3978	1.003702	1.01167	0.7938
0.399	1.00673	1.01148	0.4718
0.3991	1.006982	1.01448	0.7446
0.5623	1.003213	1.00841	0.5180
0.5623	1.003213	1.00841	0.5180
0.3991	1.006982	1.01448	0.7446
0.399	1.00673	1.01148	0.4718
0.3978	1.003702	1.01167	0.7938
0.3978	1.003702	1.00735	0.3634
0.3965	1.000422	1.00993	0.9504
0.3963	0.999917	1.0036	0.3683



FEM width set as 150 * d to approximate an infinite plate

Multiple Cracked Holes
Axial Load Case

We use the current AFGROW Advanced Model solution for two unequal through cracks at a hole and apply corrections for cracked, adjacent holes using the method of compounding.

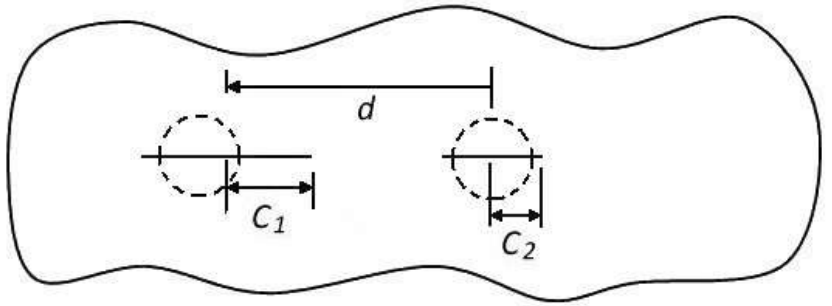


Crack Approaching a Hole

Two Possible Corrections

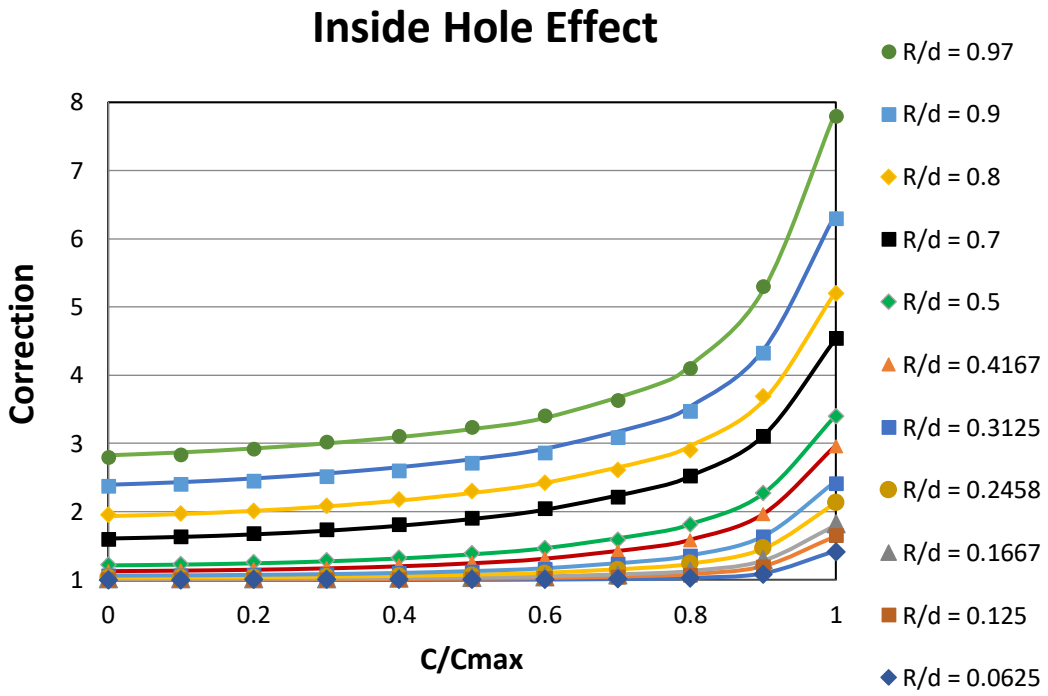
If the crack(s) at an adjacent hole are small (<= R/3), then we use the correction from the baseline reference for a through crack approaching a hole.

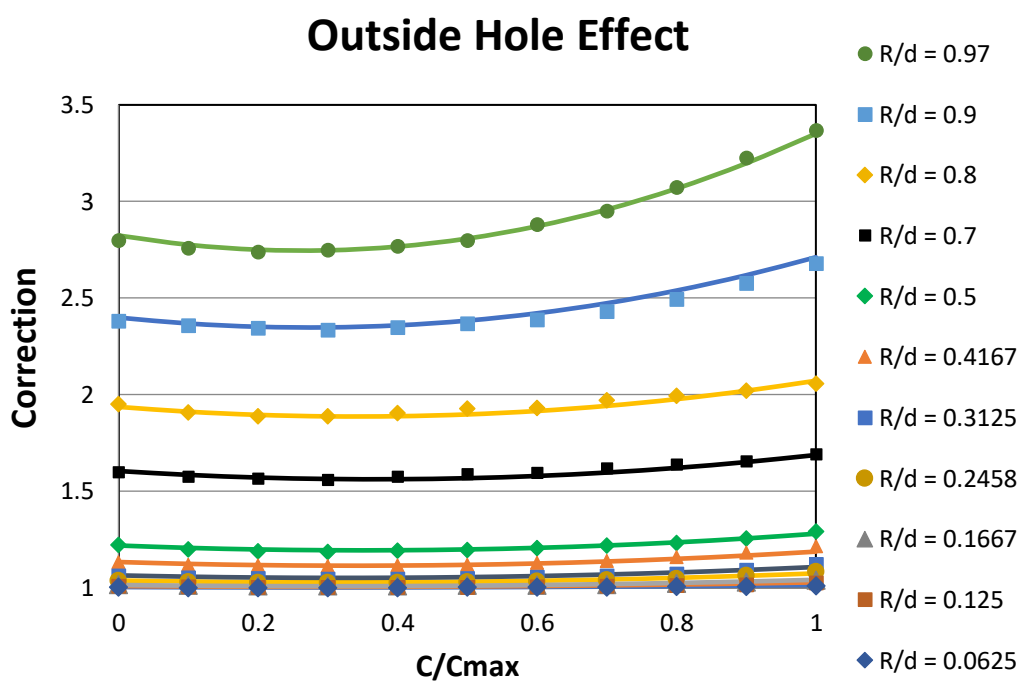
If the crack(s) at an adjacent hole are larger (> R/3) , we use the correction for a crack approaching another crack. This correction was explained in previous slides.



Crack Approaching a Crack

Through Crack Approaching a Hole
Correction

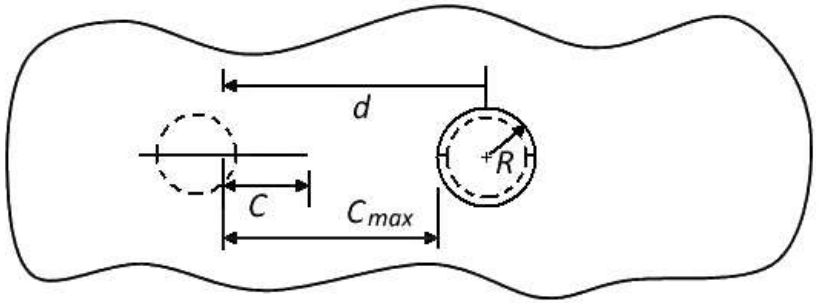




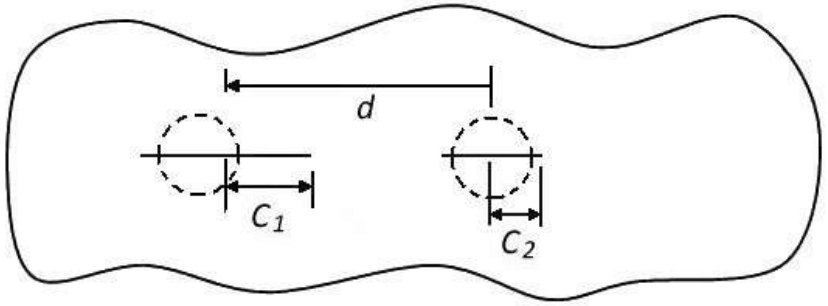
Curve fit solutions available in the baseline reference

Multiple Cracked Holes
Solution Procedure

- To solve for any number of holes, start from the hole of interest, calculate the beta solution for a given crack tip using the Advanced Model Solution for one or two non-symmetric cracks with no adjacent holes. Calculate the beta correction value for each adjacent cracked hole using the appropriate correction model for each hole from 3 through i (total number of holes).
- The inside crack tip is toward the adjacent hole and the outside crack tip is on the opposite side of the adjacent hole.
- AFGROW will allow 3 <= i <= 9 (odd number)
- The method of compounding is used to calculate the final beta correction for each crack tip. $Correction_{total} = Correction_1 * Correction_2 * \ldots * Correction_{(i-1)}$



Crack Approaching a Hole



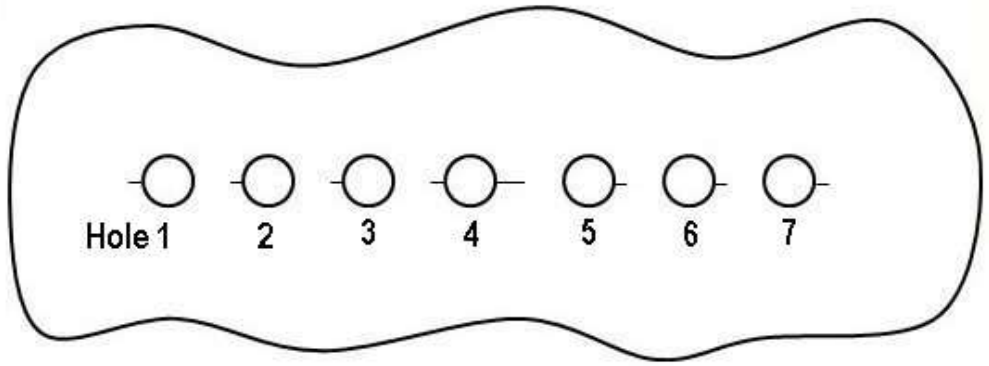
Crack Approaching a Crack

Multiple Cracked Holes
FEM Validation

Hole Dia.	Spacing	Pin Load	ByPass	Thickness	Width	Height
0.25	4D	0	10	0.04	50	250

Cp	Cs
0.05	0.005

	Stress Intensity							
	Hole 1	Hole 2	Hole 3	Hole 4		Hole 5	Hole 6	Hole 7
K	3.165	3.201	3.213	3.291	7.228	3.215	3.201	3.165
	Beta							
Beta	2.525	2.554	2.564	2.626	1.824	2.565	2.554	2.525
Equation	2.494	2.517	2.521	2.624	1.784	2.521	2.516	2.494
Diff (%)	-1.231	-1.466	-1.645	-0.084	-2.202	-1.715	-1.474	-1.234



Cp	Cs
0.25	0.1

	Stress Intensity							
	Hole 1	Hole 2	Hole 3	Hole 4		Hole 5	Hole 6	Hole 7
K	8.080	8.270	8.401	10.380	10.410	8.495	8.284	8.084
	Beta							
Beta	1.442	1.475	1.499	1.852	1.175	1.516	1.478	1.442
Equation	1.406	1.440	1.466	1.849	1.183	1.480	1.442	1.407
Diff (%)	-2.471	-2.376	-2.221	-0.154	0.670	-2.380	-2.413	-2.479

Bearing Load Effect

Bearing Load Effect on Adjacent Holes

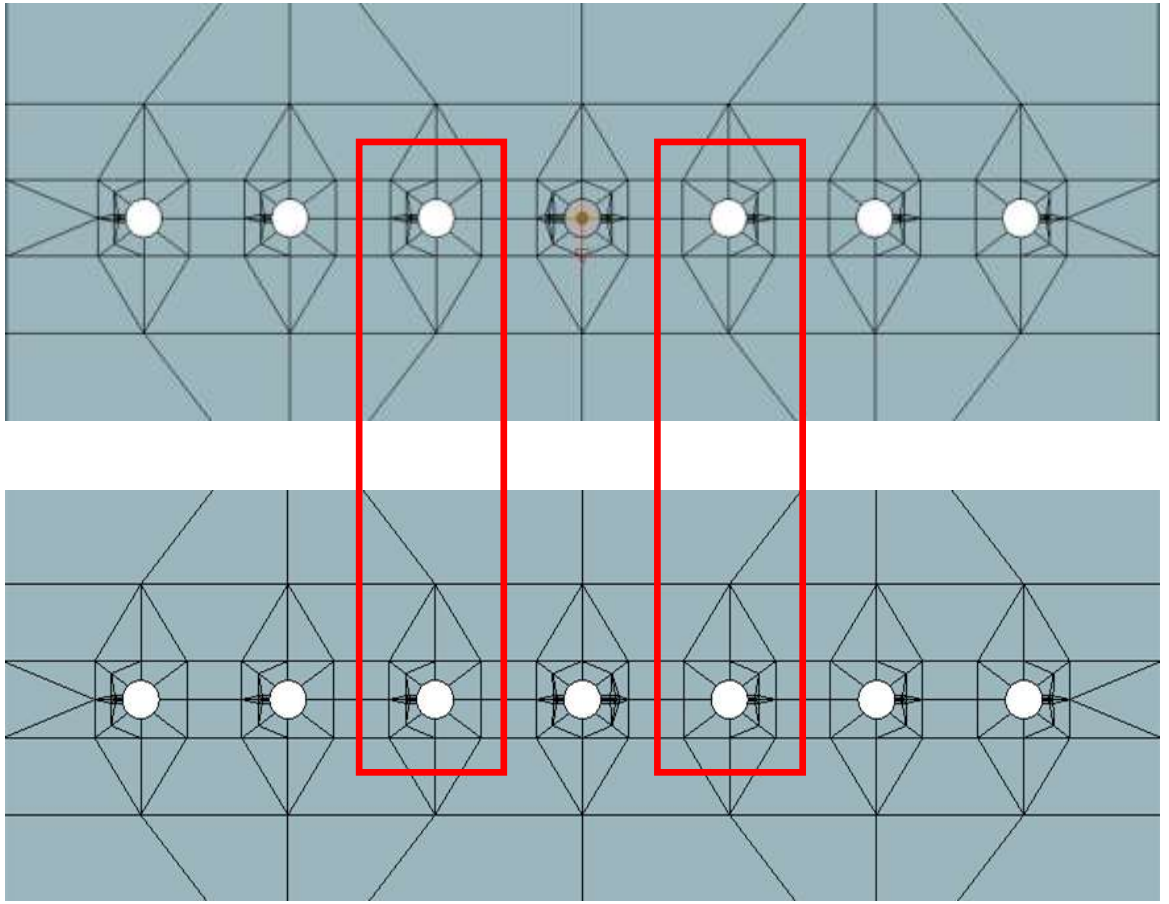
Width (in)	Total Height (in)	Thickness (in)	Hole Dia (in)	Spacing (hole dia)	ByPass (Ksi)	Pin Load (Kip)	Fastener Material
50	250	0.04	0.25	4	10	0.2	Steel

Pin Load in Center Hole Only			
Cp	Cs	Kp	Ks
0.1	0.05	10.96	11.16

Adjacent Holes	
K Left	K Right
7.819	7.832

No Bearing Load (all open holes)			
Cp	Cs	Kp	Ks
0.1	0.05	8.562	8.46

Adjacent Holes	
K Left	K Right
7.652	7.661



New Bearing Load Solution for Multiple Holes

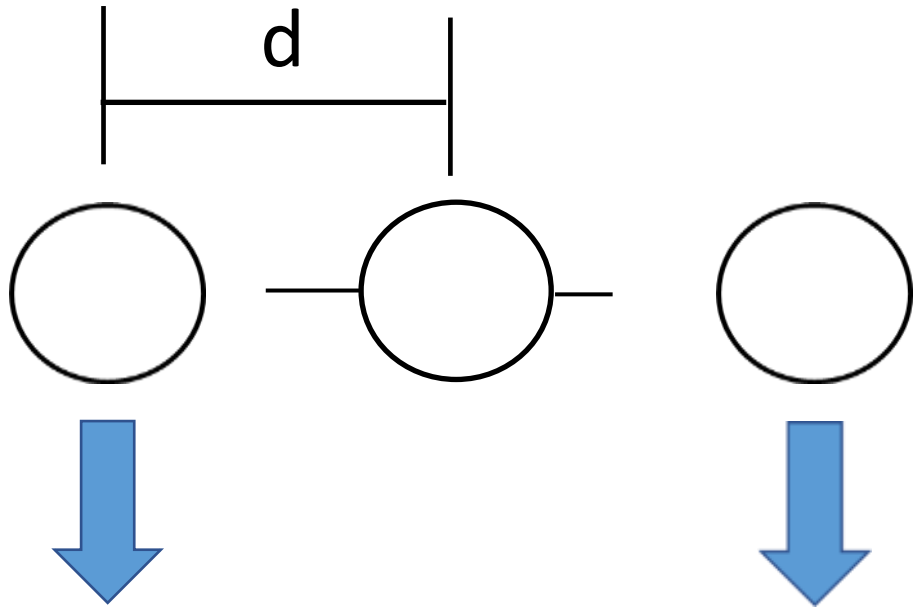
We have developed a bearing solution for the multiple hole geometry that accounts for the following effects:

- Different bearing loads at each hole
- Influence of bearing load on adjacent holes

This solution is currently being validated and we plan to include it in our upcoming new release.

Effect of Adjacent Pin Loaded Holes

Multiple FE runs were used to develop an algorithm to account for the adjacent pin loading for the adjacent holes as a function of hole spacing



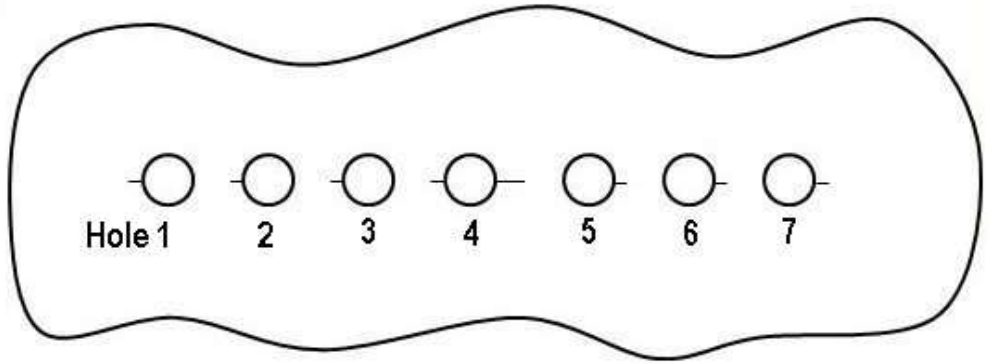
Multiple Cracked Holes
FEM Validation

Hole Dia.	Spacing	Pin Load	ByPass	Thickness	Width	Height
0.25	4D	0.4	10	0.04	50	250

	Cp	Cs						
	0.05	0.005						
	Stress Intensity							
	Hole 1	Hole 2	Hole 3	Hole 4		Hole 5	Hole 6	Hole 7
K	8.433	8.418	8.341	8.602	13.87	8.358	8.422	8.435
Equation	7.758	7.855	7.901	8.246	14.412	7.908	7.856	7.758
Diff (%)	-8.003	-6.684	-5.275	-4.143	3.909	-5.390	-6.718	-8.022

	Cp	Cs						
	0.075	0.025						
	Stress Intensity							
	Hole 1	Hole 2	Hole 3	Hole 4		Hole 5	Hole 6	Hole 7
K	12.830	12.980	12.980	13.930	14.360	13.000	12.990	12.830
Equation	12.842	13.028	13.121	14.312	14.725	13.137	13.030	12.843
Diff (%)	0.096	0.367	1.089	2.745	2.540	1.050	0.306	0.101

	Cp	Cs						
	0.1	0.05						
	Stress Intensity							
	Hole 1	Hole 2	Hole 3	Hole 4		Hole 5	Hole 6	Hole 7
K	13.710	14.000	14.070	15.570	14.880	14.090	14.000	13.710
Equation	14.183	14.425	14.552	16.161	15.228	14.573	14.428	14.184
Diff (%)	3.453	3.036	3.426	3.794	2.339	3.429	3.057	3.460

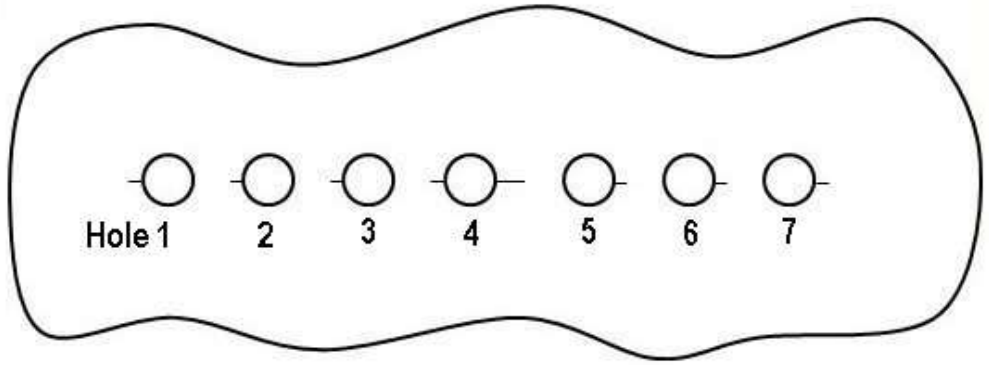


	Cp	Cs						
	0.25	0.1						
	Stress Intensity							
	Hole 1	Hole 2	Hole 3	Hole 4		Hole 5	Hole 6	Hole 7
K	13.850	14.360	14.600	18.240	16.030	14.750	14.380	13.860
Equation	14.451	14.806	15.064	18.711	16.511	15.208	14.825	14.457
Diff (%)	4.341	3.103	3.177	2.580	2.999	3.103	3.094	4.309

Multiple Cracked Holes
FEM Validation

		Hole 4	Other Holes				
Hole Dia.	Spacing	Pin Load	Pin Load	ByPass	Thickness	Width	Height
0.25	3D	0.5	0.25	10	0.04	50	250

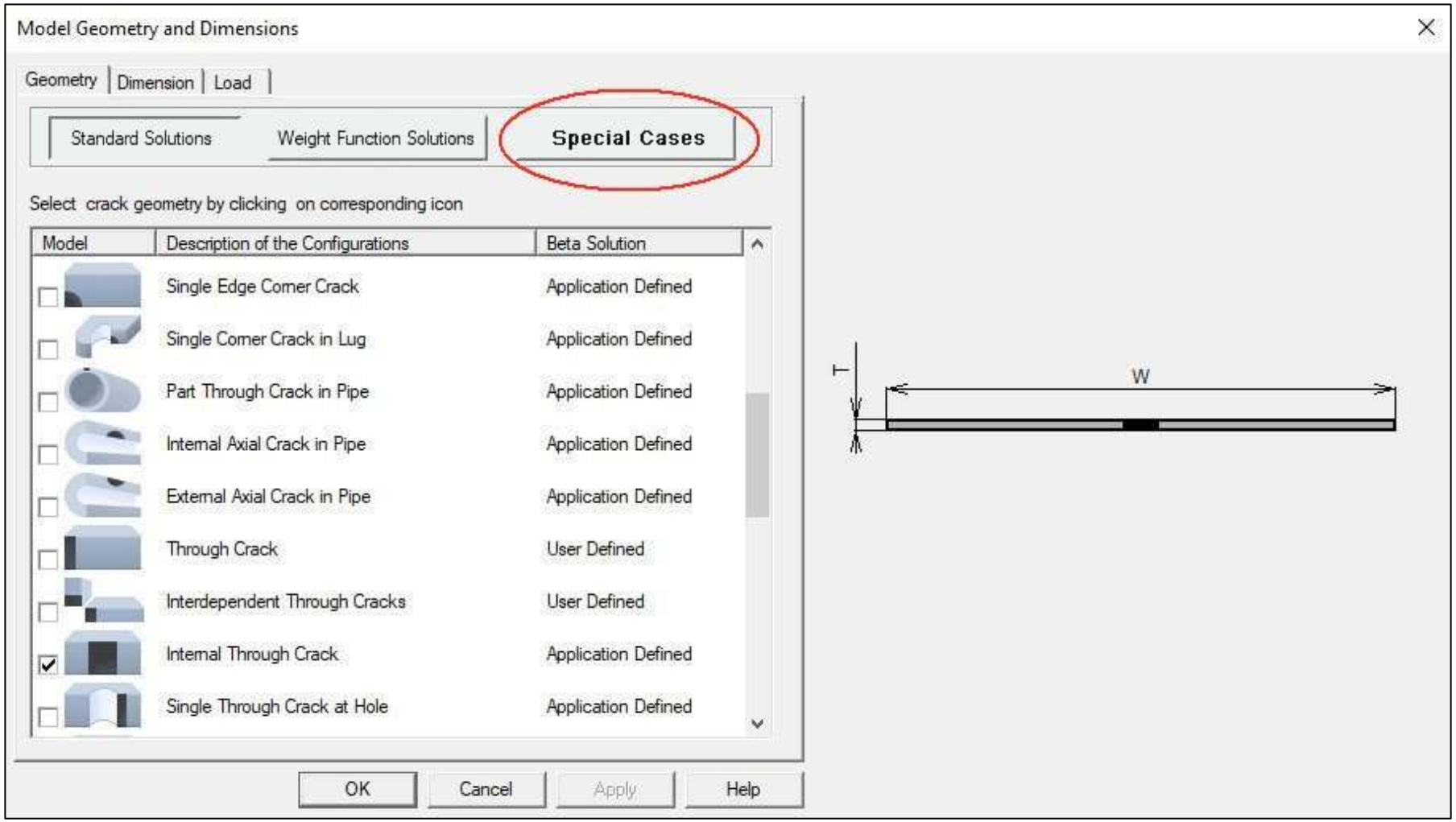
	Cp	Cs						
	0.1	0.05						
	Stress Intensity							
	Hole 1	Hole 2	Hole 3	Hole 4		Hole 5	Hole 6	Hole 7
K	11.690	12.230	12.530	17.560	16.670	12.590	12.240	11.700
Equation	11.872	12.223	12.915	17.884	16.638	12.977	12.228	11.874
Diff (%)	1.559	-0.057	3.070	1.844	-0.195	3.076	-0.097	1.483



		Hole 4	Other Holes				
Hole Dia.	Spacing	Pin Load	Pin Load	ByPass	Thickness	Width	Height
0.25	6D	0.5	0.25	10	0.04	50	250

	Cp	Cs						
	0.1	0.05						
	Stress Intensity							
	Hole 1	Hole 2	Hole 3	Hole 4		Hole 5	Hole 6	Hole 7
K	10.950	11.030	11.110	16.250	15.230	11.120	11.030	10.950
Equation	11.165	11.230	11.513	16.636	15.369	11.517	11.231	11.165
Diff (%)	1.965	1.815	3.624	2.376	0.911	3.574	1.820	1.966

Implementation



Proposed Special Cases

Multiple Through Cracks in an Infinite Plate

- Axial load case
- 3 to 7 cracks

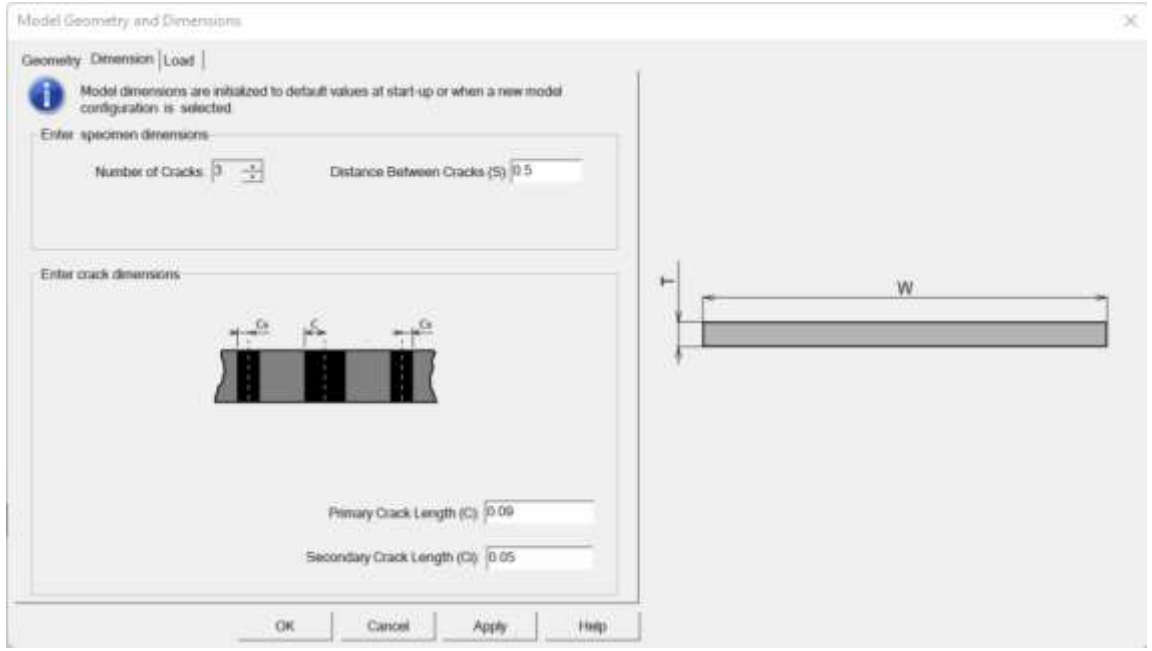
A secondary crack is added on each side of the model to simulate an infinite plate condition for all cracks in the model

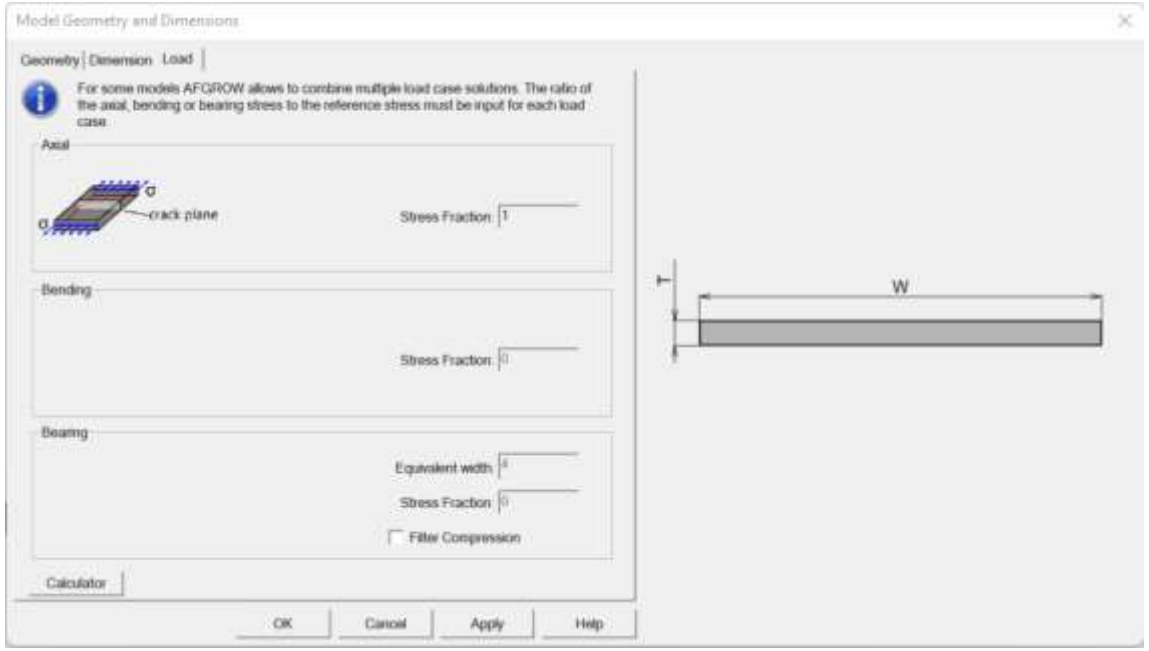
Multiple Through Cracked Holes in an Infinite Plate (Continuing Damage)

- Axial and bearing load cases
- Primary and Secondary Crack at the Center Hole
- Single Secondary Crack on Outside of each adjacent hole (2, 4, or 6 holes)

A secondary cracked hole is added on each side of the model to simulate an infinite plate condition for all cracks in the model

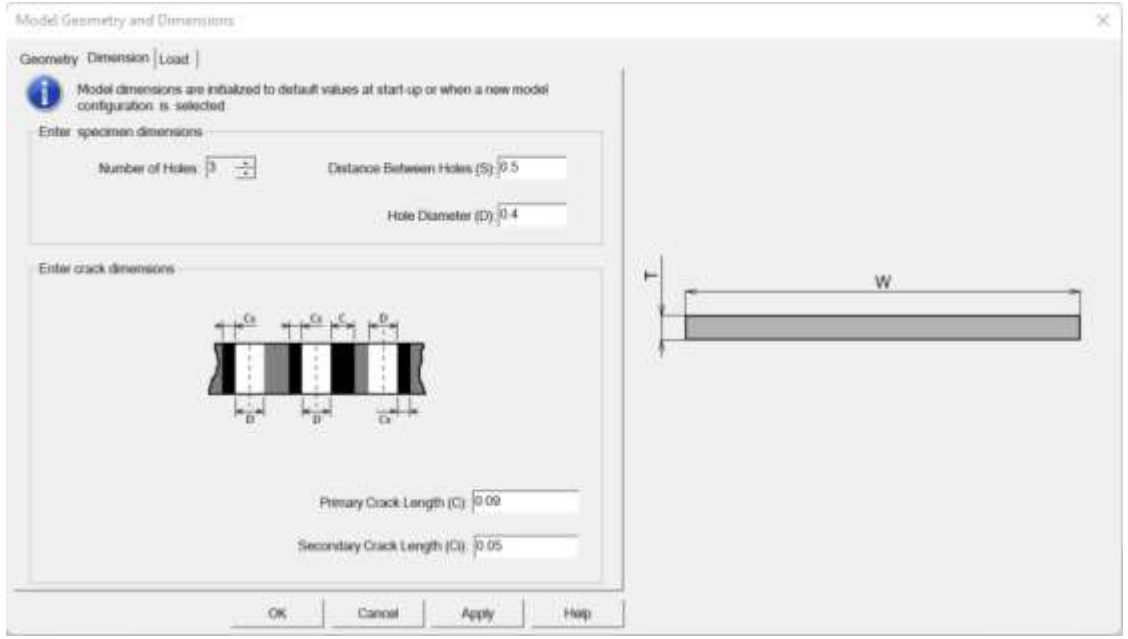
Multiple Through Cracks

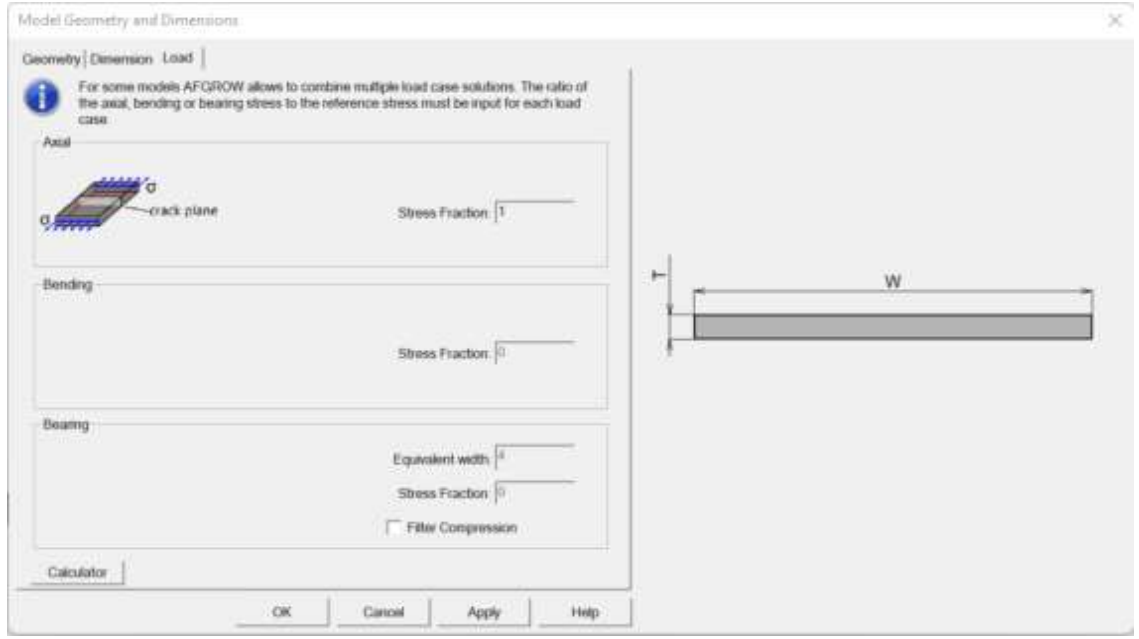




Multiple Holes

Will Allow combinations of Axial, Bending, and Bearing Loading





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Questions/Comments?