Stress Intensity Factor Solution for Two, Independent Through-the-Thickness Cracks at an Offset Pin Loaded Hole

Cordell E. Smith
James A. Harter

LexTech, Inc.
8285 Rhine Way
Centerville, OH 45458

Outline

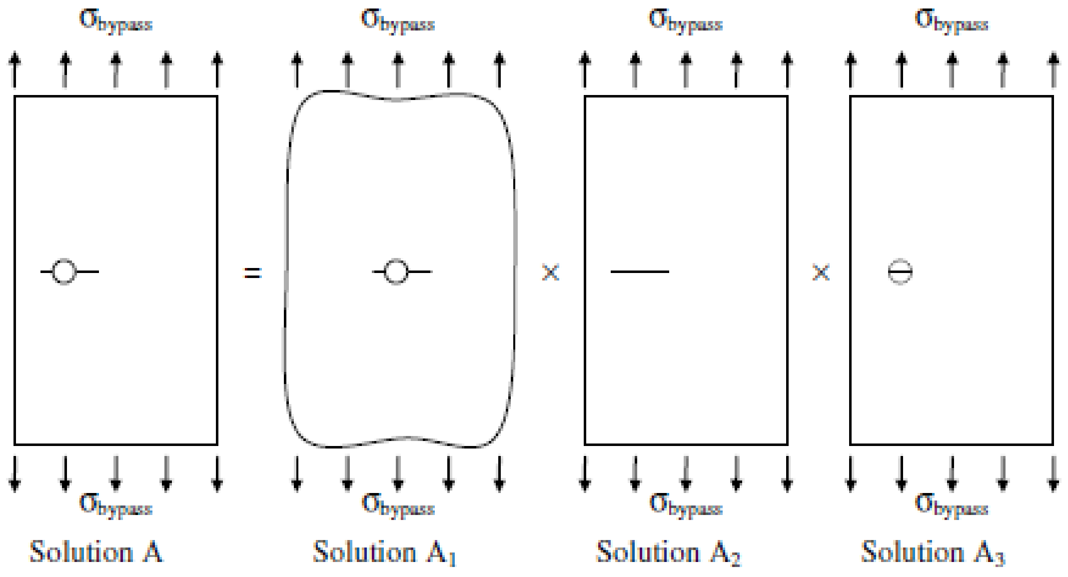
- Background
- Bombardier and Liao Solution
- Modifications made to Bombardier and Liao Solution
- Results and Comparisons
- Conclusion

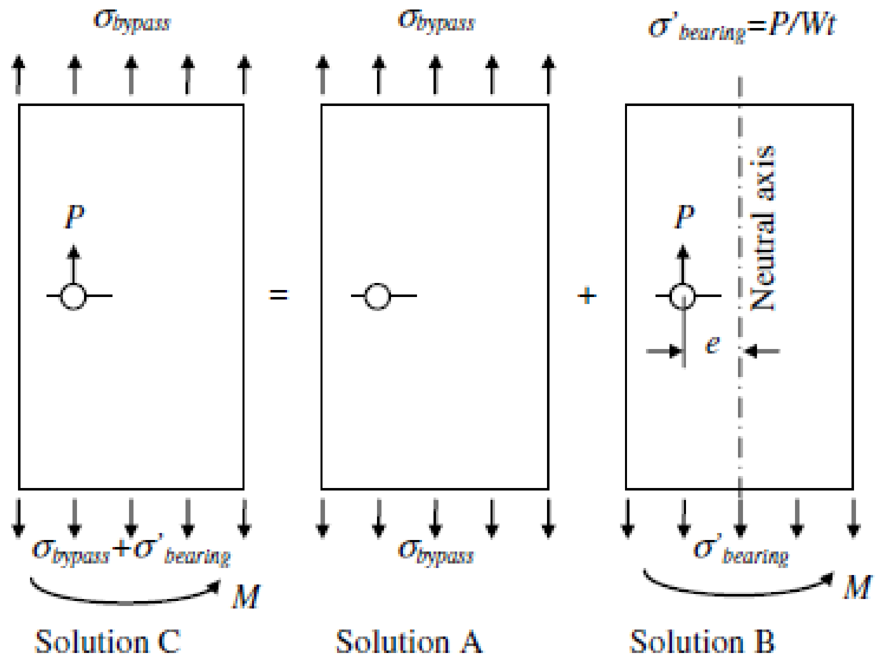
Background

- To resolve a problem with AFGROW's Advanced Model Interface where pin loaded corner cracked holes transitioned to become through cracks under pure axial loading, LexTech has implemented a new closed-form advanced SIF solution for two, independent through-the-thickness cracks at an offset pin loaded hole. This new solution is a modification of the Bombardier and Liao solution, and it will be available in AFGROW version 5.3.

Bombardier and Liao Solution

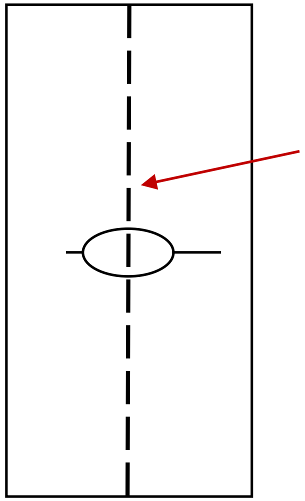
- The Bombardier and Liao solution is based on compounding and superposition of know solutions for a crack at an open hole and a wedge loaded through-the -thickness crack geometries. The solution also used FEM results to develop a table lookup correction to account for in-plane bending .





Neutral Axis Modification

- The original solution assumed that there is no in-plane bending as long as the pen loaded hole is located at the neutral axis (originally defined as the center of the plate).
- Several cases were examined for a centered hole with different crack lengths on either side to determine the effect of the resulting asymmetry on in-plane bending. Available FEM results indicated that hole/crack asymmetry can have a significant effect on the K-solution. A different in-plane bending correction factor was then determined using the plate neutral axis, based on the plate width, hole geometry, and current crack lengths, as the primary correction parameter.



Neutral axis is now a function of plate width, hole offset and crack lengths

Wedge Solution Modification for Short Crack Lengths

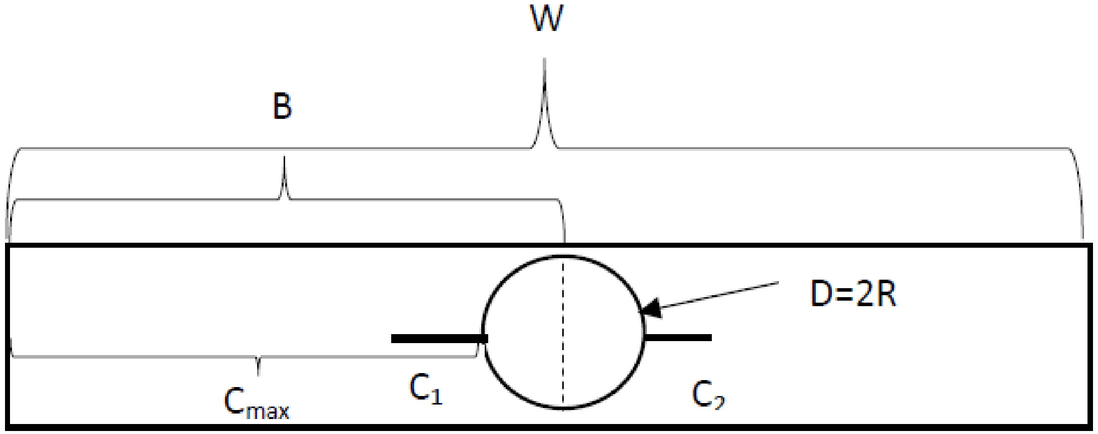
- Changes were also made to the infinite plate wedge loaded through crack portion of the Bombardier/Liao solution.
- The wedge solution uses the sum of each crack length and hole diameter as the total wedge loaded crack length.
- After comparing this solution to known results for several cases, it was determined that there were errors at both short and long crack lengths. The observed errors for the short crack lengths ($C/R < 1$) are believed to have occurred because the internal through crack wedge solution is not a good approximation for cases with relatively short crack lengths.
- A correction to account for the hole effect was developed for $C/R < 1$ based on known FEM results.

Wedge Solution Modification for Large Crack Lengths

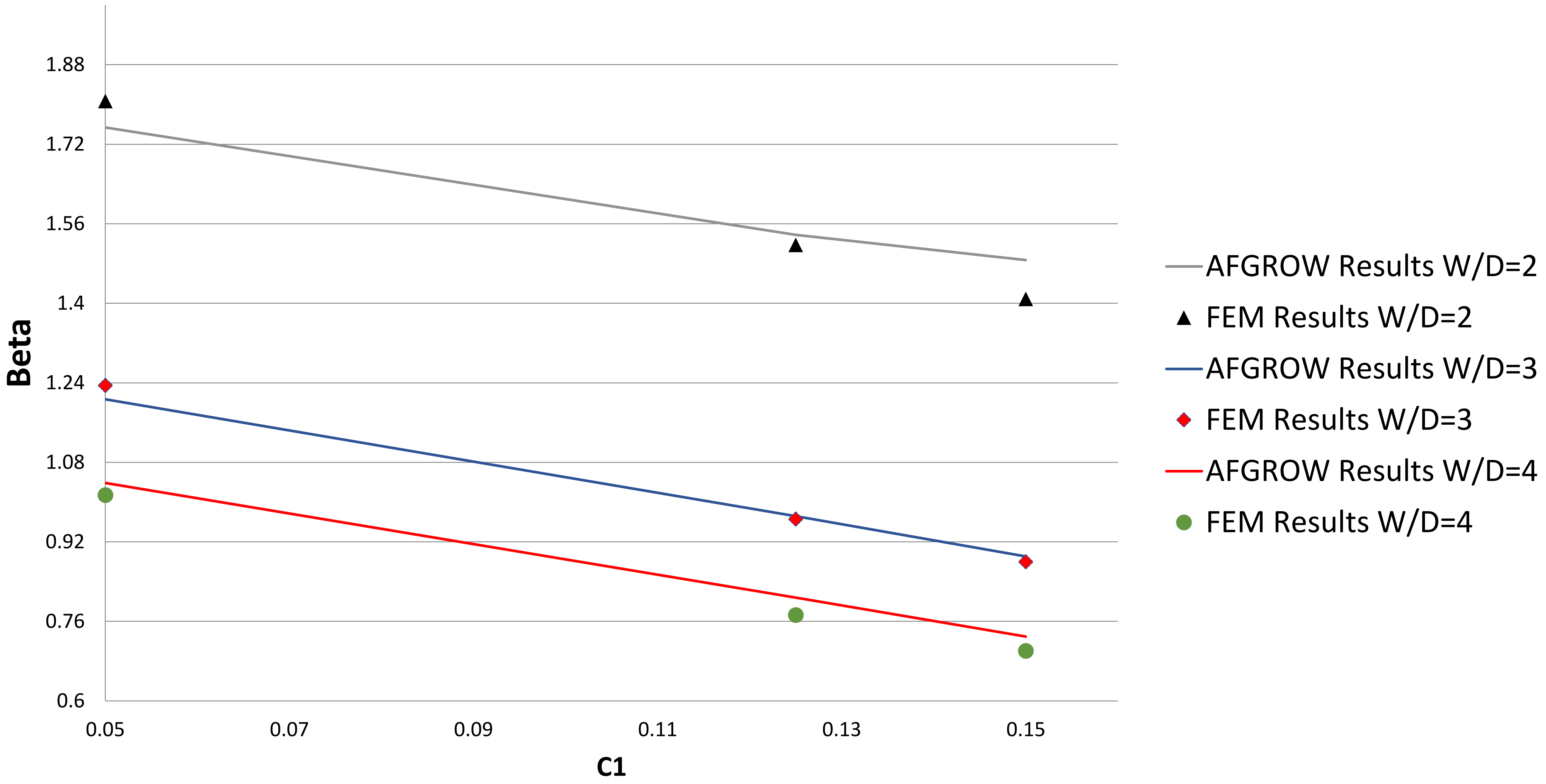
- For larger cracks (C/R > 1), the solution still has some issues when the hole edge distance becomes small (B/D < 2).
- For larger cracks in general, the compounded Bombardier/Liao solution appeared to be slightly low (~3-4%) for all crack lengths compared to existing FEM results. Another correction was implemented to the infinite plate wedge solution to account for this difference.

Model Configuration to Validate the New Solution

- Results were compared for:
- C/Cmax (maximum crack length) up to 80%
- B (offset) from 1 to 3.25
- W (plate width) from 2 to 7
- D (diameter) was 1 for all cases



Center Hole AFGROW and FEM Comprisons

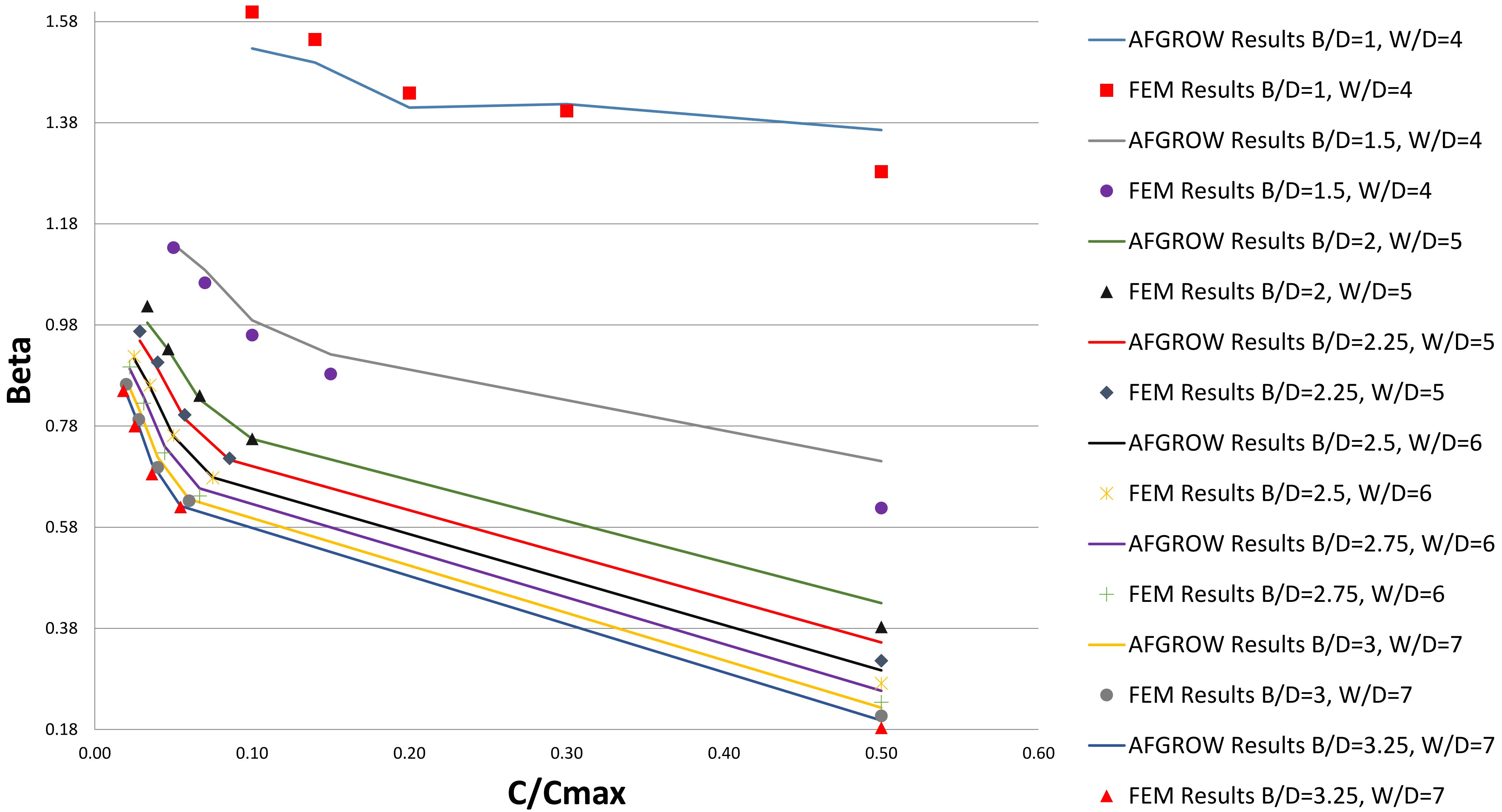


Centered Hole Results and Comparisons

C/Cmax>0.5

LEFT	RIGHT	Centered Hole						AFGROW		%DIFFERENCE		FEM	
C1	C2	W	C1/Cmax	C2/Cmax	C1/R	C2/R	W/D	BETA 1	BETA 2	BETA 1	BETA 2	BETA 1	BETA 2
0.08	0.1	2	0.16	0.20	0.16	0.2	2	1.6297	1.5703	-0.304	1.564	1.6347	1.5461
0.12	0.095	2	0.24	0.19	0.24	0.19	2	1.5343	1.5945	2.766	0.344	1.4930	1.5890
0.05	0.125	2	0.10	0.25	0.1	0.25	2	1.7535	1.5119	-2.964	3.750	1.8071	1.4573
0.125	0.15	2	0.25	0.30	0.25	0.3	2	1.5378	1.4992	1.322	4.018	1.5177	1.4413
0.15	0.07	2	0.30	0.14	0.3	0.14	2	1.487	1.6799	5.550	-2.211	1.4088	1.7179
0.1	0.3	2	0.20	0.60	0.2	0.6	2	1.6234	1.6529	-7.632	21.842	1.7575	1.3566
0.125	0.3	2	0.25	0.60	0.25	0.6	2	1.5595	1.6542	-6.749	20.474	1.6724	1.3731
0.4	0.2	2	0.80	0.40	0.8	0.4	2	2.3688	1.4863	35.136	-10.815	1.7529	1.6665
0.08	0.1	3	0.08	0.10	0.16	0.2	3	1.08	1.0115	-0.655	0.061	1.08712	1.01088
0.12	0.095	3	0.12	0.10	0.24	0.19	3	0.965	1.041	0.698	-0.069	0.95831	1.04172
0.05	0.125	3	0.05	0.13	0.1	0.25	3	1.2069	0.9363	-2.281	0.469	1.23507	0.93193
0.125	0.15	3	0.13	0.15	0.25	0.3	3	0.9716	0.909	0.588	1.249	0.96592	0.89778
0.15	0.07	3	0.15	0.07	0.3	0.14	3	0.8907	1.1353	1.248	-1.189	0.87972	1.14896
0.1	0.3	3	0.10	0.30	0.2	0.6	3	1.084	0.7272	-2.302	5.669	1.10955	0.68819
0.125	0.3	3	0.13	0.30	0.25	0.6	3	1.0147	0.7334	-1.811	5.449	1.03342	0.6955
0.4	0.2	3	0.40	0.20	0.8	0.4	3	0.7149	0.8894	8.857	-3.133	0.65674	0.91817
0.08	0.1	4	0.05	0.07	0.16	0.2	4	0.9158	0.8492	6.031	6.363	0.86371	0.7984
0.12	0.095	4	0.08	0.06	0.24	0.19	4	0.8028	0.877	4.343	4.155	0.76939	0.84202
0.05	0.125	4	0.03	0.08	0.1	0.25	4	1.0384	0.7759	2.376	3.717	1.0143	0.7481
0.125	0.15	4	0.08	0.10	0.25	0.3	4	0.8078	0.7461	4.525	4.525	0.77283	0.7138
0.15	0.07	4	0.10	0.05	0.3	0.14	4	0.7296	0.9684	4.105	3.517	0.70083	0.9355
0.1	0.3	4	0.07	0.20	0.2	0.6	4	0.9156	0.5502	3.404	5.374	0.88546	0.52214
0.125	0.3	4	0.08	0.20	0.25	0.6	4	0.8476	0.556	3.519	5.465	0.81879	0.52719
0.4	0.2	4	0.27	0.13	0.8	0.4	4	0.5102	0.7208	6.983	2.210	0.4769	0.70522

Offset Hole AFGROW and FEM Comparisons



LexTech Offset Hole Results and Comparisons

AFGROW.NET

LEFT	RIGHT	Offset Hole					AFGROW		%DIFFERENCE		FEM	
C1	C2	C1/C1max	C1/R	C2/R	W/D	B/D	BETA 1	BETA 2	BETA 1	BETA 2	BETA 1	BETA 2
0.05	0.05	0.10	0.2	0.2	4	1	1.527	1.246	-4.504	4.956	1.599	1.187
0.07	0.1	0.14	0.28	0.4	4	1	1.499	1.028	-2.967	5.269	1.545	0.976
0.1	0.08	0.20	0.4	0.32	4	1	1.41	1.129	-2.003	5.292	1.439	1.072
0.15	0.2	0.30	0.6	0.8	4	1	1.417	0.793	0.947	2.27	1.404	0.775
0.25	0.125	0.50	1	0.5	4	1	1.366	1.045	6.433	0.831	1.283	1.036
0.05	0.05	0.05	0.2	0.2	4	1.5	1.14	1.017	0.601	3.282	1.133	0.985
0.07	0.1	0.07	0.28	0.4	4	1.5	1.089	0.842	2.375	5.591	1.063	0.797
0.1	0.08	0.10	0.4	0.32	4	1.5	0.989	0.919	3.048	5.547	0.96	0.871
0.15	0.2	0.15	0.6	0.8	4	1.5	0.922	0.649	4.408	5.122	0.883	0.617
0.5	0.125	0.50	2	0.5	4	1.5	0.711	0.918	14.95	-10.84	0.618	1.03
0.05	0.05	0.03	0.2	0.2	5	2	0.985	0.935	-3.251	-6.038	1.018	0.995
0.07	0.1	0.05	0.28	0.4	5	2	0.931	0.767	-0.185	-3.255	0.933	0.793
0.1	0.08	0.07	0.4	0.32	5	2	0.833	0.84	-0.928	-3.879	0.841	0.873
0.15	0.2	0.10	0.6	0.8	5	2	0.755	0.582	-0.075	-3.946	0.755	0.606
0.75	0.125	0.50	3	0.5	5	2	0.43	0.87	12.32	10.35	0.383	0.788
0.05	0.05	0.03	0.2	0.2	5	2.25	0.949	0.922	-1.92	-4.675	0.967	0.967
0.07	0.1	0.04	0.28	0.4	5	2.25	0.893	0.76	-1.466	-2.884	0.906	0.782
0.1	0.08	0.06	0.4	0.32	5	2.25	0.795	0.829	-0.95	-2.93	0.802	0.854
0.15	0.2	0.09	0.6	0.8	5	2.25	0.713	0.58	-0.401	-2.51	0.716	0.595
0.875	0.125	0.50	3.5	0.5	5	2.25	0.352	0.867	11.36	-7.69	0.316	0.939
0.05	0.05	0.03	0.2	0.2	6	2.5	0.913	0.888	-0.536	-3.562	0.918	0.921
0.07	0.1	0.04	0.28	0.4	6	2.5	0.857	0.724	-0.402	-2.163	0.861	0.74
0.1	0.08	0.05	0.4	0.32	6	2.5	0.76	0.794	-0.179	-2.078	0.761	0.811
0.15	0.2	0.08	0.6	0.8	6	2.5	0.679	0.543	0.152	-2.55	0.678	0.557
1	0.125	0.50	4	0.5	6	2.5	0.297	0.845	9.437	-6.395	0.271	0.902
0.05	0.05	0.02	0.2	0.2	6	2.75	0.893	0.88	-0.398	-3.141	0.897	0.908
0.07	0.1	0.03	0.28	0.4	6	2.75	0.837	0.72	1.397	-0.984	0.825	0.727
0.1	0.08	0.04	0.4	0.32	6	2.75	0.74	0.788	1.756	-0.917	0.727	0.795
0.15	0.2	0.07	0.6	0.8	6	2.75	0.657	0.542	2.324	-0.921	0.642	0.547
1.125	0.125	0.50	4.5	0.5	6	2.75	0.256	0.843	9.633	-6.141	0.234	0.899
0.05	0.05	0.02	0.2	0.2	7	3	0.871	0.857	0.99	-2.121	0.863	0.876
0.07	0.1	0.03	0.28	0.4	7	3	0.815	0.696	2.727	-0.115	0.793	0.697
0.1	0.08	0.04	0.4	0.32	7	3	0.718	0.764	2.837	0.056	0.698	0.764
0.15	0.2	0.06	0.6	0.8	7	3	0.635	0.517	0.503	-1.654	0.632	0.526
1.25	0.125	0.50	5	0.5	7	3	0.223	0.83	7.652	-4.901	0.207	0.873
0.05	0.05	0.02	0.2	0.2	7	3.25	0.859	0.852	1.047	-1.925	0.85	0.868
0.07	0.1	0.03	0.28	0.4	7	3.25	0.802	0.693	2.838	0.066	0.78	0.692
0.1	0.08	0.04	0.4	0.32	7	3.25	0.706	0.76	2.994	0.252	0.685	0.758
0.15	0.2	0.05	0.6	0.8	7	3.25	0.622	0.517	0.294	-1.208	0.62	0.523
1.375	0.125	0.50	5.5	0.5	7	3.25	0.198	0.829	7.817	-4.836	0.183	0.871

Conclusion

- This new solution appears to be reasonable for W/D and B/D greater than 2. The new solution is generally within 5% of the FEM results for most of the cases that were tested. For short hole edge distances (B/D < 2), the results showed larger differences. When C/Cmax > 0.5, the differences also increase above 5-10% for all cases shown in Table 2. These differences will tend to have a relatively minor effect on total crack growth life since most of the life for a majority of structures is expended at shorter crack lengths.
- The new solution is an important improvement for the AFGROW Advanced Model Interface since it will allow more accurate predictions to be made for Advanced Models including hole bearing loads after transition to a through crack case. Based on the available FEM results, the following recommended limits should be considered when using this solution:
  - W/D > 2,
  - B/D > 1.5,
  - For C/Cmax > 0.5, user's should be aware that the solution is very likely to have more significant error.