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Modeling the Growth and Interaction of Fractures

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Research Objective

Develop an accurate, efficient numerical tool for fracture mechanics analysis. Capabilities of the method include the modeling of multiple site damage and the simulation of crack propagation.

Approach

The fracture is modeled using a distribution of edge dislocations. Fundamental solutions for dislocations in an infinite medium, in the neighborhood of a circular inhomogeneity, and near a bi-material interface are incorporated into the procedure to allow exceptionally accurate modeling of fracture geometries involving these types of inhomogeneities. To model arbitrary (finite) domains under general boundary conditions, a combination of the dislocation methodology and boundary element techniques is used. The dislocation scheme is a natural means to model the crack(s), and the boundary element method is an effective way to model the region in which the crack is embedded. The hybrid scheme is relatively easy to use and is very accurate.

Accomplishment Description

The methodology has been well proven for cracks in infinite domains (e.g. Fig.1) and for cracks at circular inhomogeneities (e.g. Fig.2), near free surfaces (e.g. Fig.3) and near bi-material interfaces (e.g. Fig.4). Interaction of cracks with multiple surfaces have also been treated efficiently by modeling the boundaries with either distributed dislocations or with linear force elements (e.g. Figs.5,6,7). The experience with modeling cracks in finite domains has proven that the methodology can be used effectively for modeling arbitrary plane, linear bodies. Our experience with both dislocation and force-collocation methods for the boundary has led us to believe that the best way to model the boundary will be to adopt standard boundary element techniques, while retaining the dislocation method to properly treat the cracks. A standard boundary element procedure has recently been implemented, and the coupling of this code with the dislocation procedure is under way. In addition, the possibility of extending the dislocation methodology to model cracks in plates under bending has recently been explored, and the results of this preliminary investigation indicate that the extension can be made in a natural way.

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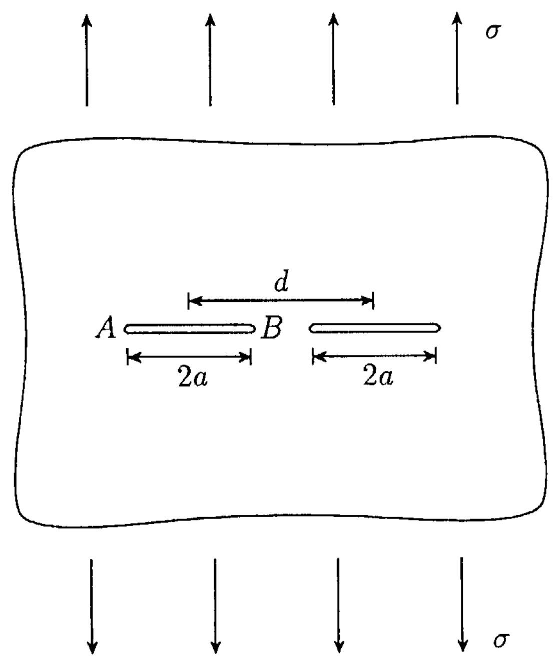


$2a/d$	# Coll Pts	K_{1A}/K_{1A}^{exa}	K_{1B}/K_{1B}^{exa}
0.10	4	1.0011	1.0011
0.30	4	1.0011	1.0011
0.50	4	1.0011	1.0004
0.70	4	1.0009	0.9973
0.90	8	1.0001	0.9946
0.94	10	1.0000	0.9930
0.98	18	0.9997	0.9926

Fig.1 Interaction of crack pair in an infinite medium. Table gives computed results normalized by exact solution, as a function of relative crack spacing $2a/d$. Number of collocation points on each crack selected such that error is less than one percent.

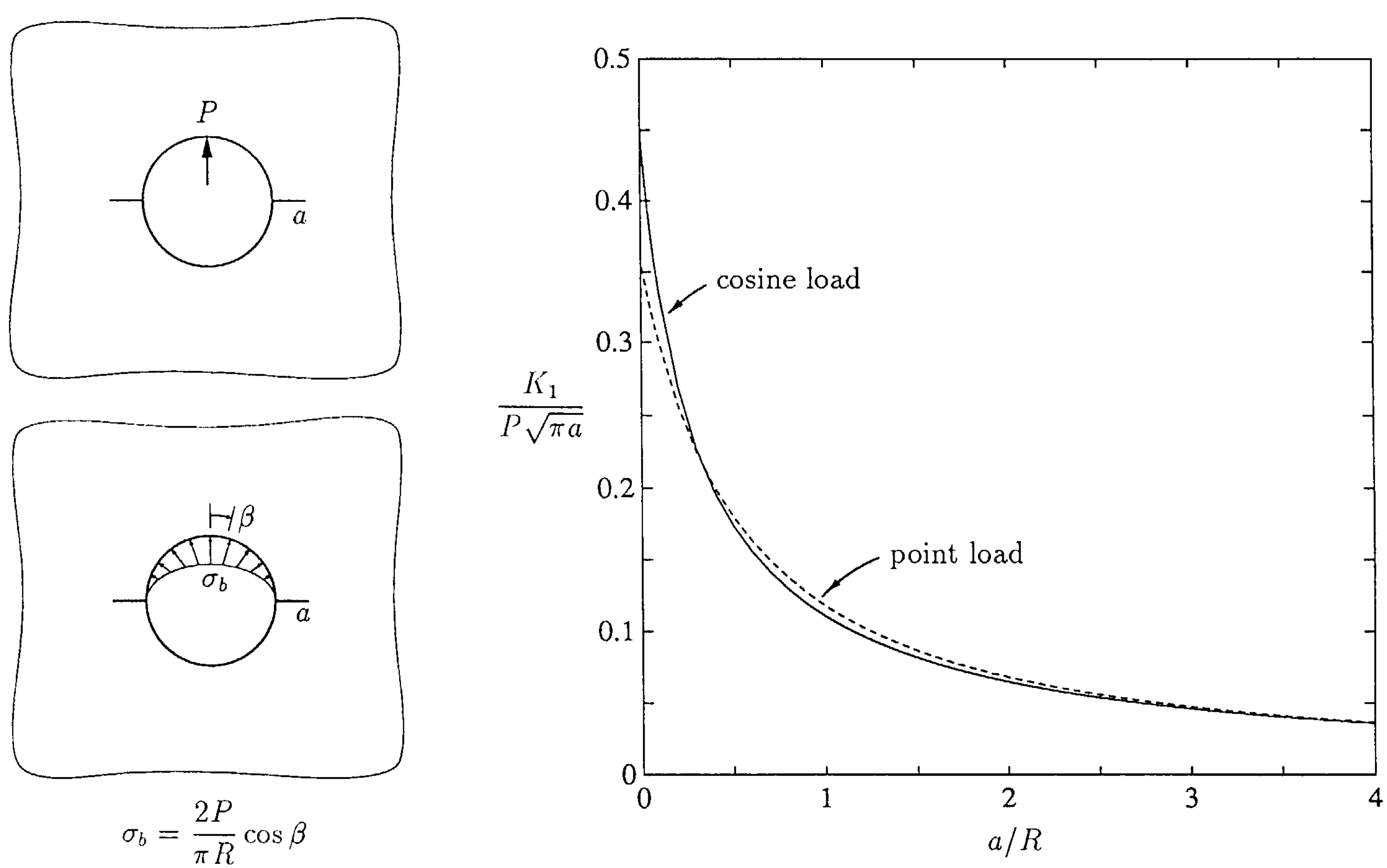


Fig.2a Cracks emanating from hole in infinite medium. Comparison of K_1 for pin loaded hole and hole loaded with distributed (cosine) loading. In both cases, net vertical force is P.

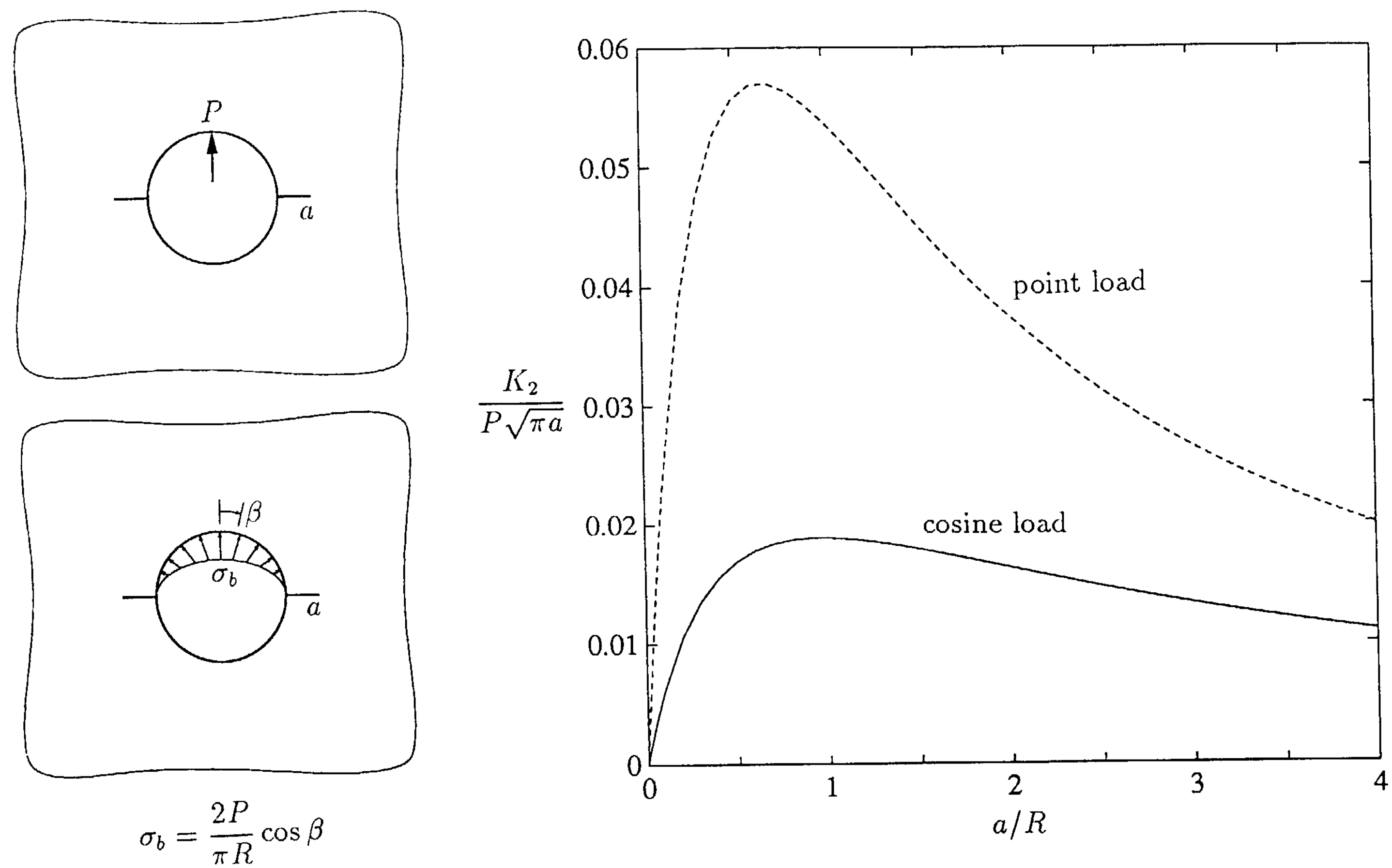
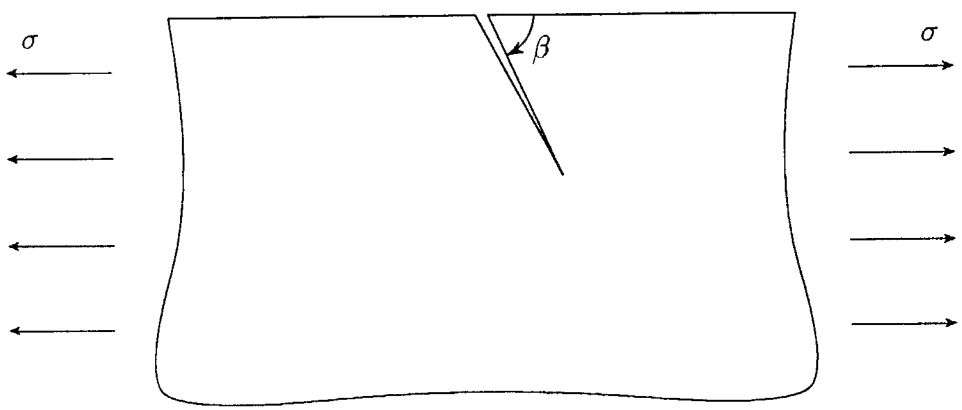
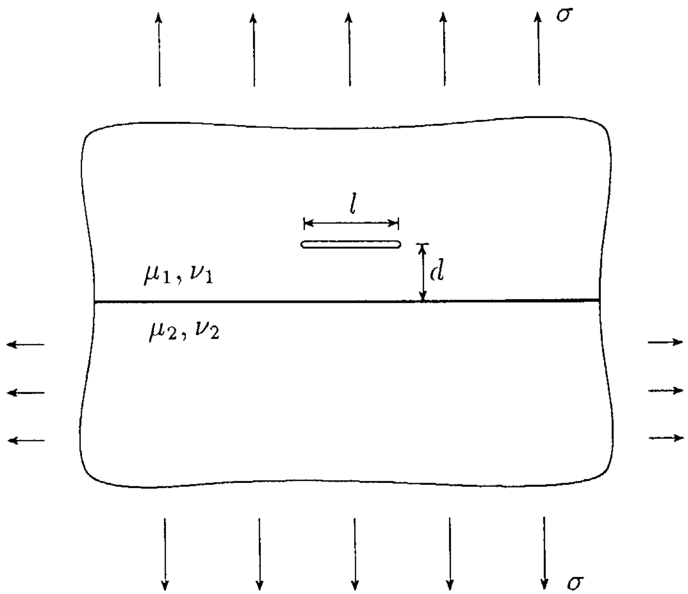


Fig.2b Cracks emanating from hole in infinite medium. Comparison of K_2 for pin loaded hole and hole loaded with distributed (cosine) loading. In both cases, net vertical force is P.



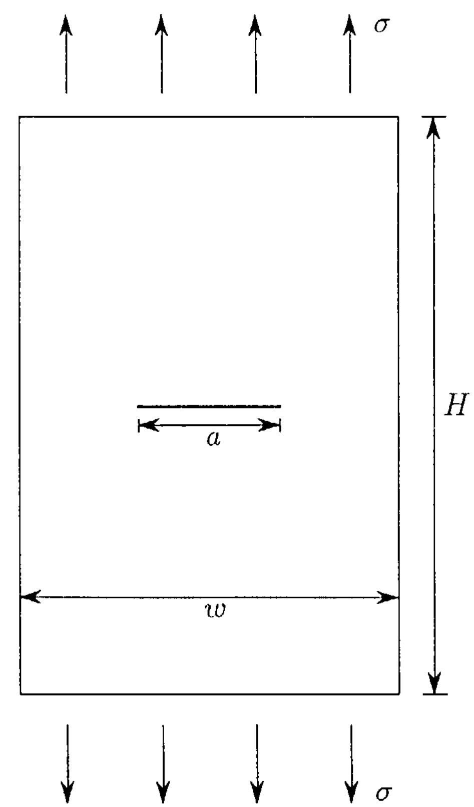
inclined angle	K_1/K_1^{hbk}	K_2/K_2^{hbk}
15	0.998	1.001
30	0.998	1.000
45	1.000	1.000
60	1.000	1.000
90	1.000	1.000

Fig.3 Crack emanating from free surface. Tabulated results show K_1 and K_2 normalized by handbook values for various inclination angles β.



μ_2/μ_1	$d/l = 0.1$		$d/l = 2.0$	
	K_1/K_1^{hbk}	K_2/K_2^{hbk}	K_1/K_1^{hbk}	K_2/K_2^{hbk}
0.00	1.003	0.992	1.000	1.000
0.25	1.003	1.010	1.000	1.000
0.50	1.002	1.000	1.000	1.000
2.00	0.999	1.000	1.000	1.000
∞	0.997	1.000	1.000	1.000

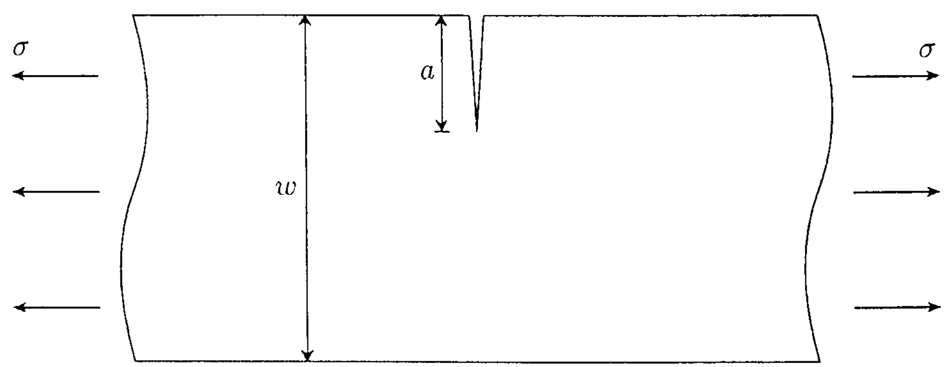
Fig.4 Crack parallel to a bi-material interface. Values of K_1 and K_2 are shown normalized by handbook results for various values of moduli ratio and relative distance of crack from interface.



a/w	F_1^{code}	F_1^{exa}
0.1	1.0063	1.0060
0.2	1.0249	1.0246
0.3	1.0581	1.0577
0.4	1.1094	1.1094
0.5	1.1856	1.1867
0.6	1.2995	1.3033

$$K_1 = \sigma\sqrt{\pi a}F_1$$

Fig.5 Results for center crack in panel ($H/w = 2$) compared with exact results for infinite strip (i.e. $H/w = \infty$). Boundaries modeled with distributed dislocations.



a/w	K_1^{code}	K_1^{Jap}
0.2	3.43589	3.42656
0.3	5.08791	5.08082
0.4	7.48759	7.47266
0.5	11.27817	11.20432

Fig.6 Results for surface crack in finite strip (i.e. edge cracked panel) compared with handbook values for various a/w. Boundaries modeled with linear traction elements.

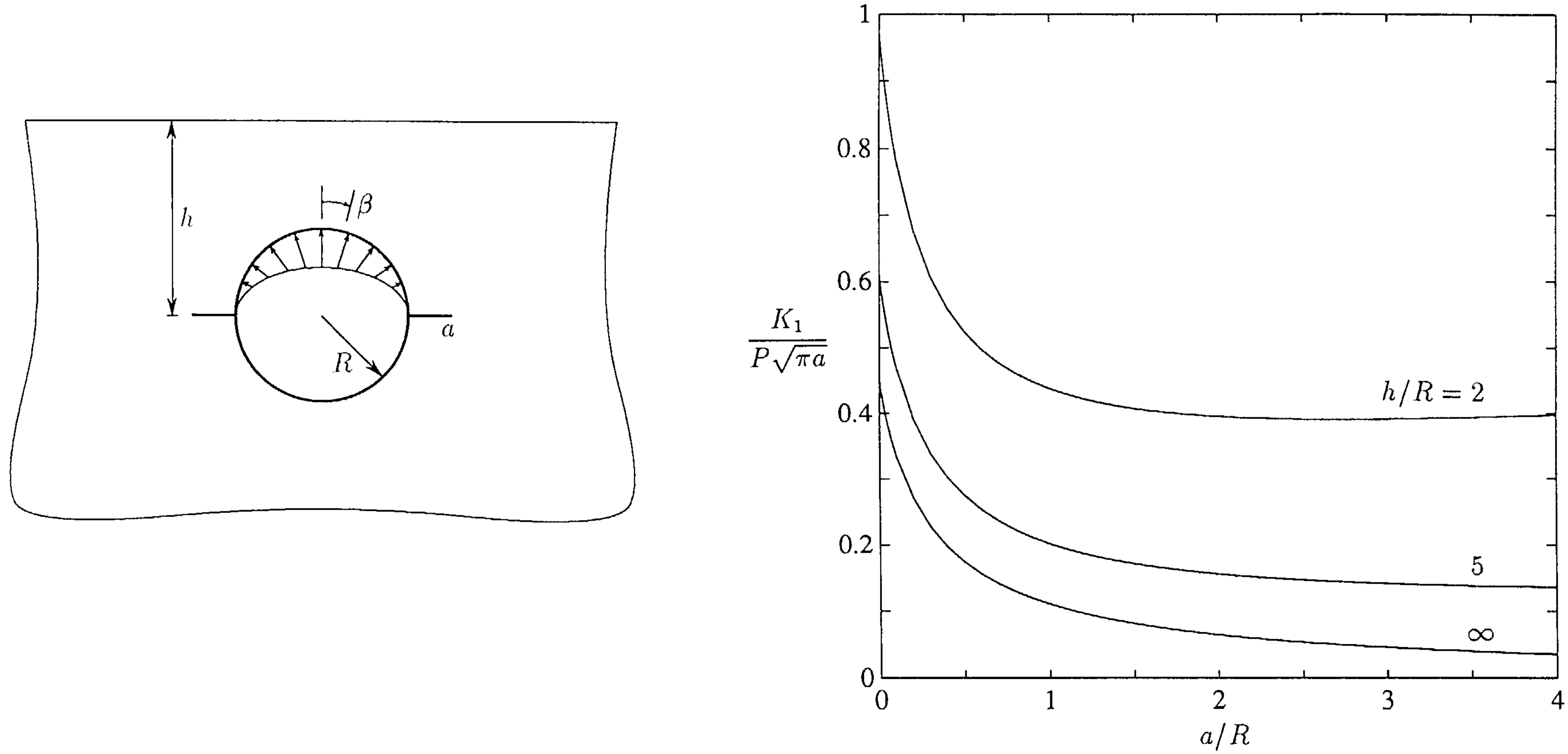


Fig.7a Cracks emanating from hole beneath half plane. Hole is subjected to cosine loading. Effect of free surface on K_1 is shown. Hole and free surface modeled with linear traction elements.

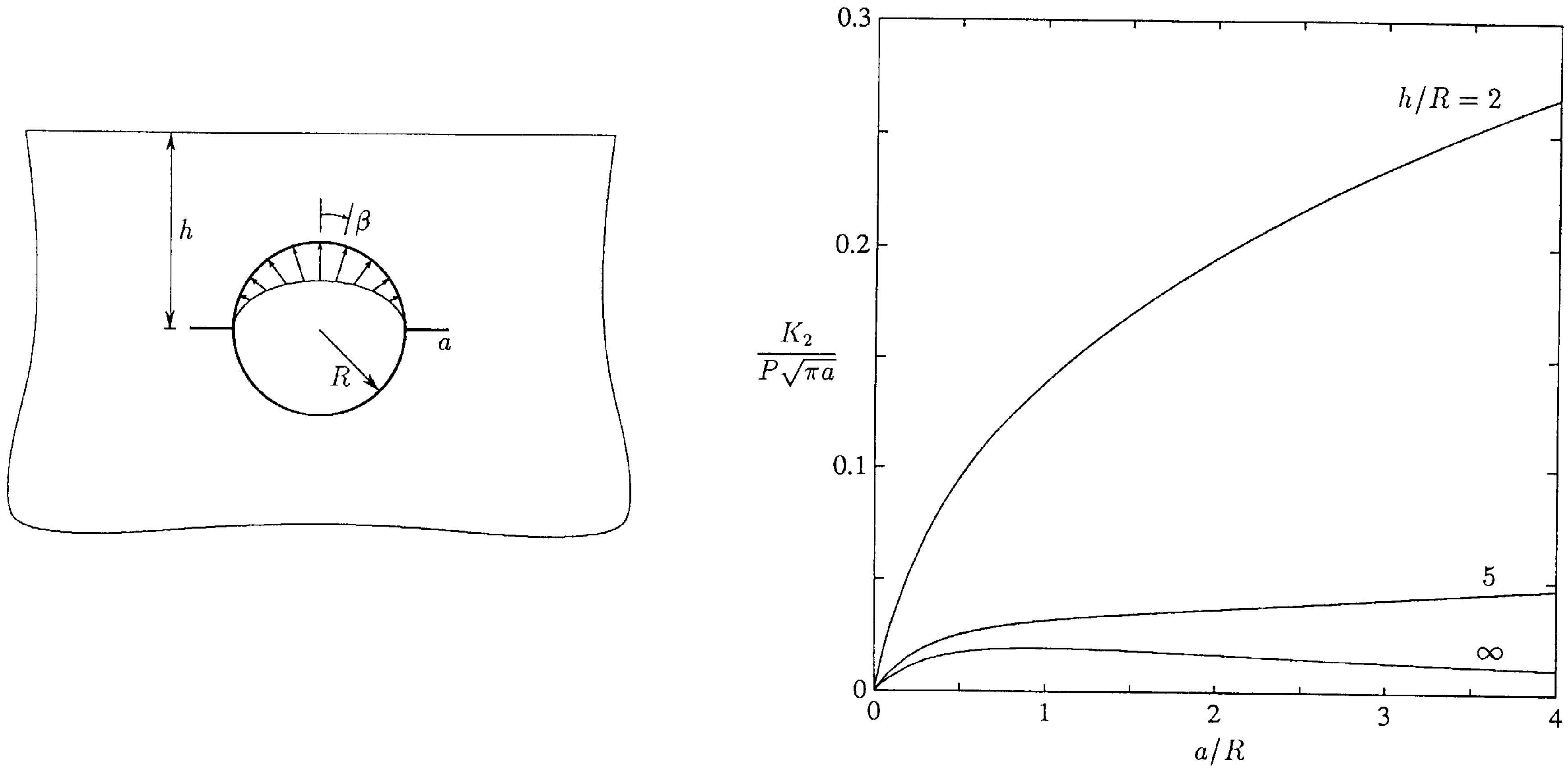


Fig.7b Cracks emanating from hole beneath half plane. Hole is subjected to cosine loading. Effect of free surface on K_2 is shown. Hole and free surface modeled with linear traction elements.