Chapter 2

GENERALIZED WAVE DIFFRACTION DIAGRAMS

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INTRODUCTION

Wave diffraction is the phenomenon in which water waves are propagated into a sheltered region formed by a breakwater or similar barrier which interrupts a portion of a regular wave train (Fig. 1). The principles of diffraction have considerable practical application in connection with the design of breakwaters as discussed by Dunham (1951) at the Long Beach Conference. The phenomenon is analogous to the diffraction of light, sound, and electromagnetic waves. Two general types of diffraction problems usually are encountered: one, the passage of waves around the end of a semi-infinite impermeable breakwater (Putnam and Arthur, 1948), and, second, the passage of waves through a gap in a breakwater (Blue and Johnson, 1949; Carr and Stelzriede, 1951). In general, the theoretical solutions have been found to apply with conservative results, that is, the predicted wave heights in the lee of a breakwater are found to be slightly larger than the height of waves that may be expected under actual conditions. The use of the diffraction theory in breakwater design is made convenient when summarized in the form of diagrams with curves of equal values of diffraction coefficients on a coordinate system in which the origin of the system is at the tip of a single breakwater (Figs. 2a-2b, and 3) or at the center of a gap (Figs. 2c, and 4-6). The diffraction coefficient in this instance is defined as the ratio of the diffracted wave height to the incident wave height and usually is designated by the symbol K'. The procedure in preparing diffraction diagrams appears elsewhere (Johnson, 1950). The purpose of this paper is to present diffraction diagrams to supplement the material of Dunham (1951). For complete details on the application of diffraction diagrams to typical harbor problems the reader is referred to this latter paper.

Semi-infinite breakwater - The generalized diffraction diagram shown in Fig. 3 can be applied to a particular breakwater problem once the characteristics of the design wave have been selected - that is, the height, period and direction of the incident wave from which protection is to be provided. The design wave is selected either from recorded wave data as described by Snodgrass (1951) or by application of the hindcasting procedure outlined by Arthur (1951). As an illustration

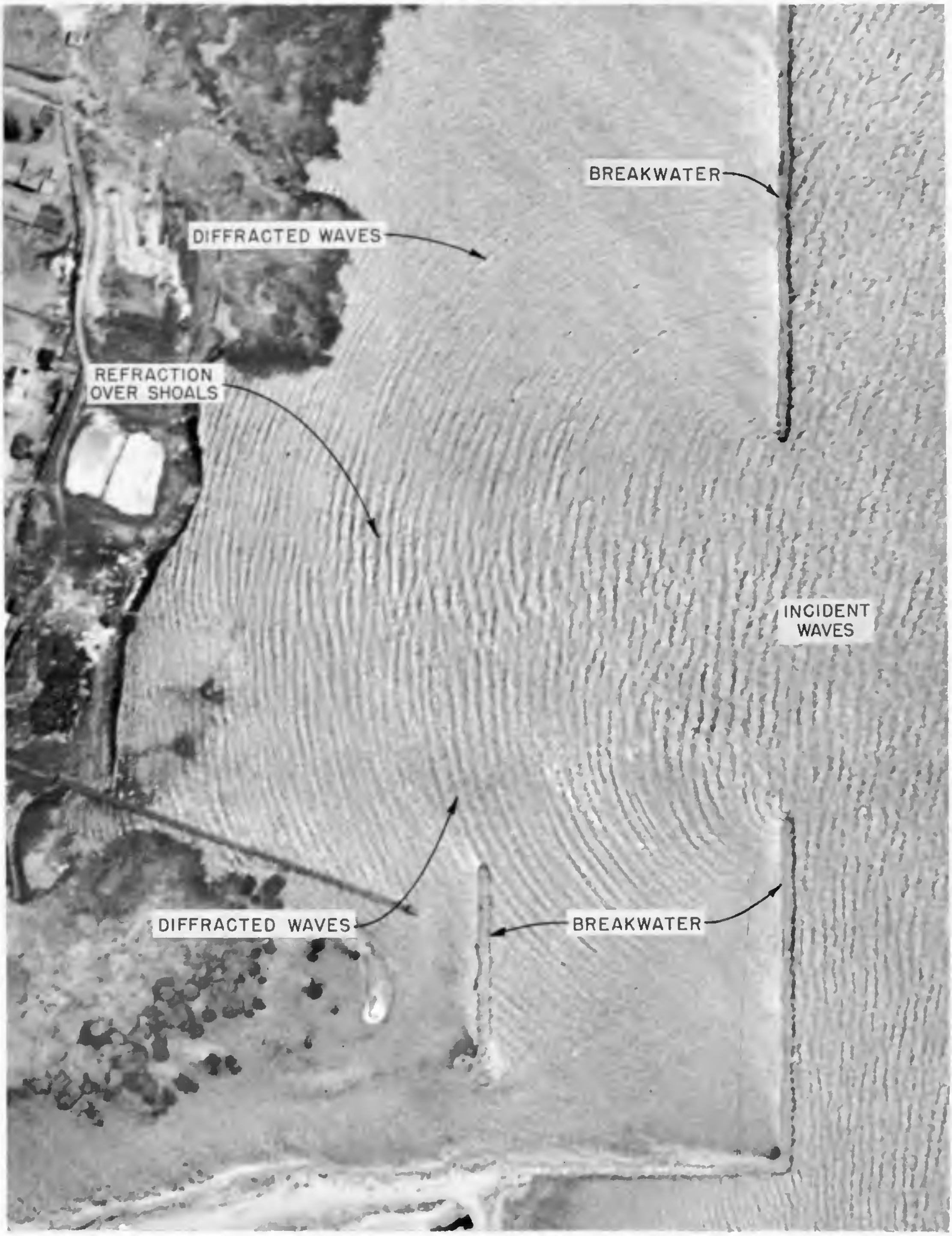


Fig. 1
Diffraction of waves at a breakwater

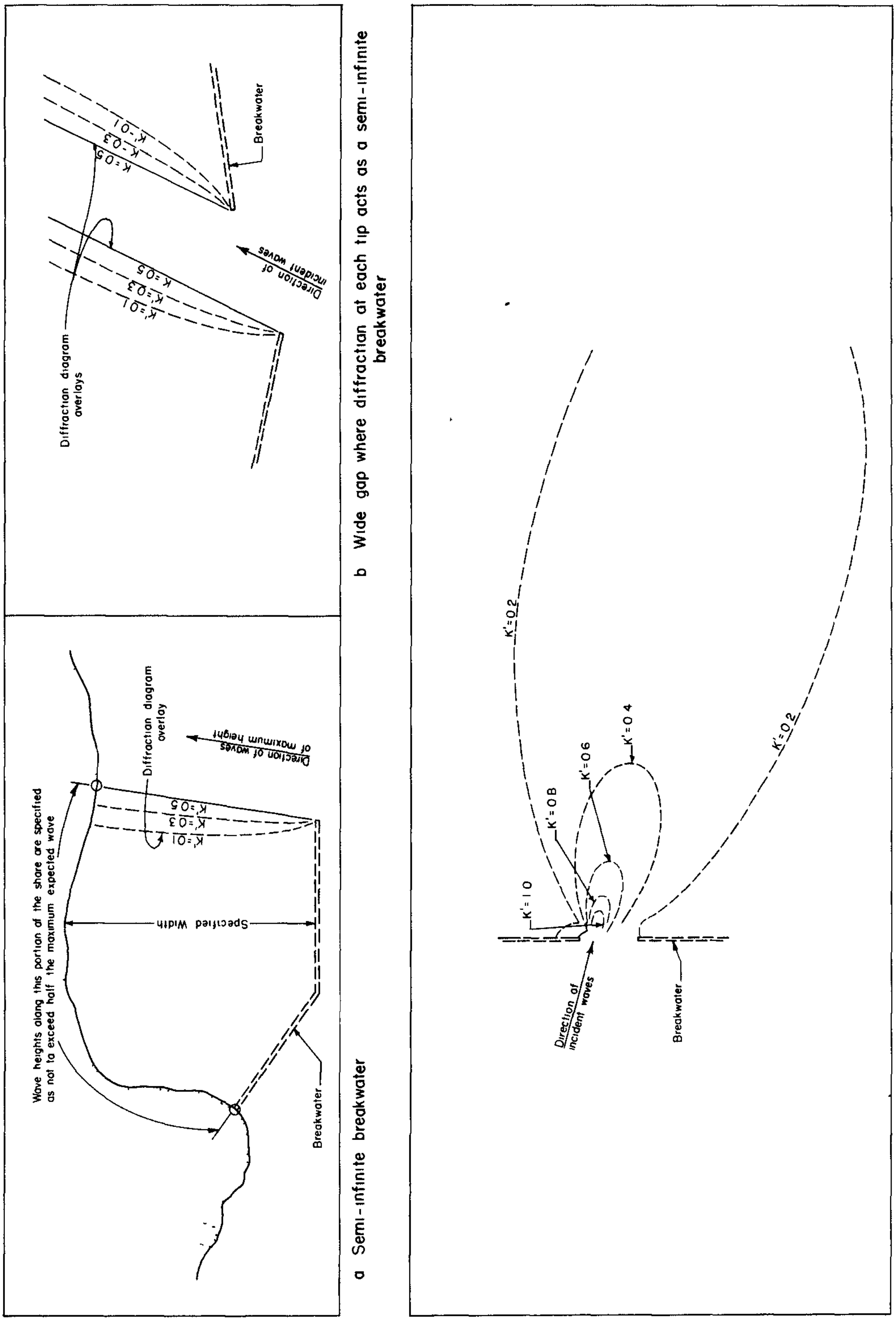


Fig. 2
Typical examples of diffraction at breakwaters

of the use of a diffraction diagram, Fig. 2a shows a map of a harbor for which protection is desired for a specified reach of the shoreline with waves approaching from the direction from which the maximum height waves occur. For a given wave period (or length) a diagram similar to Fig. 3 is plotted on transparent paper to the same length scale as the map of the harbor area. This transparent overlay then is moved over the map (keeping the geometric shadow parallel to the direction of travel) until the desired degree of protection for the selected reach of the shoreline is obtained. The location of the tip of the breakwater thus is obtained as illustrated by the final location of the overlay shown in Fig. 2a. It should be noted that the diffraction diagram shown in Fig. 3 is the same diagram as discussed by Dunham (1951) but applied to both semi-infinite breakwaters and breakwater gaps. The material summarized below presents diffraction diagrams also for gaps and permits refinement to the solution of some of the problems discussed by Dunham (1951).

Diffraction at a Breakwater Gap - The treatment of diffraction problems, as discussed in the above paragraph is concerned with waves moving past a breakwater tip with an infinite expanse of water existing away from the tip. In many harbors, however, waves move through a relatively narrow gap in a breakwater (Fig. 2c); hence, diffraction occurs at the two sides of the gap and changes in wave height in the lee of the breakwater will be different than if a single tip existed. Theories for this condition also have been developed. Experimental studies have verified the general form of the theoretical expressions for breakwater gap openings as small as a half wave length. As long as the water depth in the lee of the structure remains constant the diffraction pattern is independent of the actual depth. In natural harbors, however, this condition of uniform depth may not always occur. Instead a shoaling bottom usually exists - in which case the waves are not only diffracted, but refraction also results as the waves move further to the lee of the structure. At a considerable distance from the breakwater, it is probable that the refraction effects predominate over the diffraction effects.

Figs. 4-6 show generalized diagrams which give diffraction coefficients to the lee of breakwater gaps of various widths but with normal approach of the waves. The method of making the necessary computations of these diffraction coefficients as well as the computations for the position of the wave fronts (shown only in Fig. 5a) is presented elsewhere (Johnson, 1950; Carr and Stelzriede, 1951). These generalized diagrams, when used as transparent overlays, can be moved over a map of an area to obtain the most desirable protection, similar to the procedure illustrated in Figs. 2a-2b for a single breakwater.

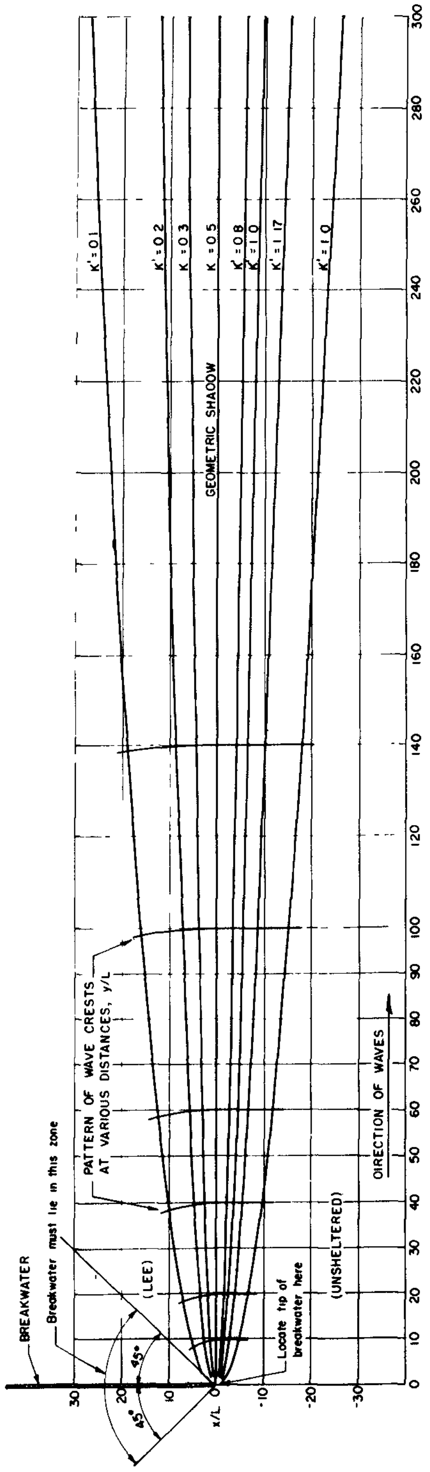


Fig. 3 Generalized diagram for diffraction at the tip of a semi-infinite breakwater

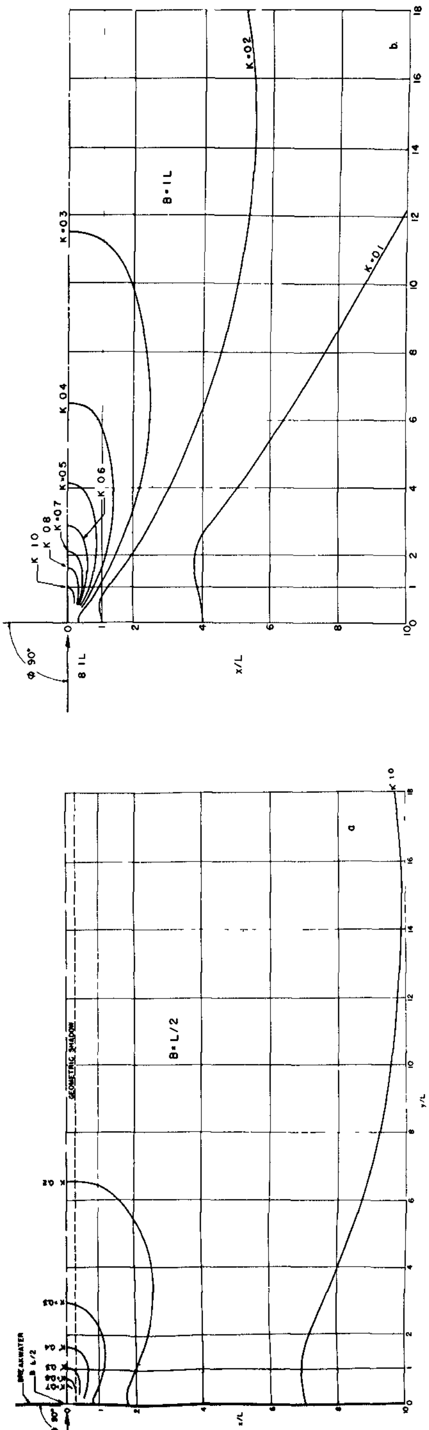
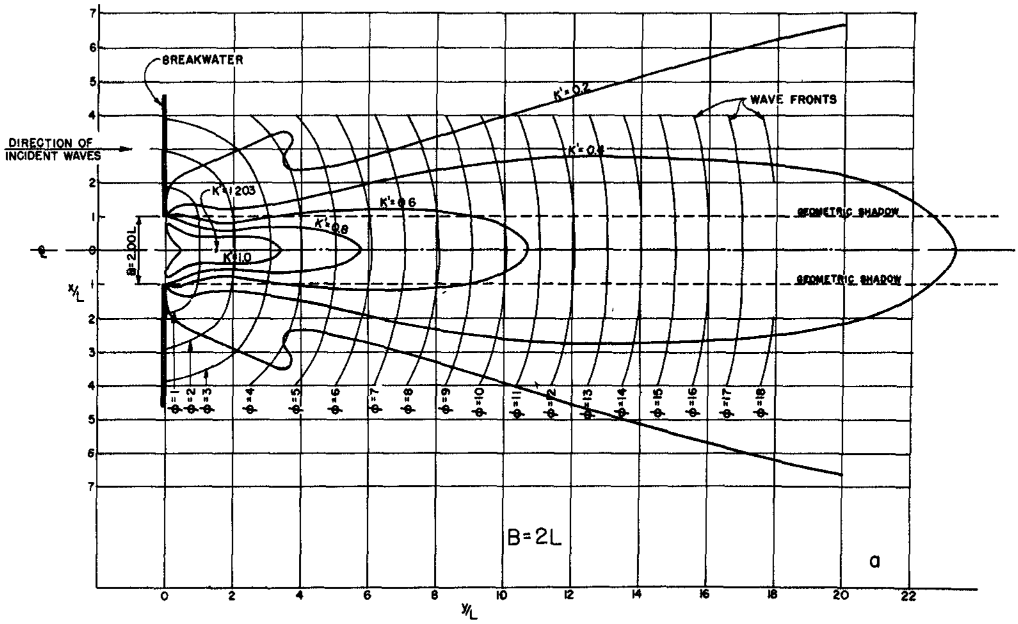


Fig. 4 Generalized diagrams for diffraction at breakwater gaps of one-half and one wave length in width (90 degree approach).

GENERALIZED DIAGRAMS

For semi-infinite breakwaters the single diagram shown in Fig. 3 is sufficient for all such breakwaters with waves approaching from any direction within the limits indicated (also see universal diagram of Dunham, 1951). In the case of breakwater gaps, however, a different diagram is required for each combination of gap width and direction of wave approach. A number of representative generalized diagrams for gaps are shown in Figs. 4-6, inclusive. These diagrams pertain to gaps which range in width from $\frac{1}{2}$ to 5 wave lengths with the direction of wave approach being normal to the gap. These diagrams cover a wide range of gap openings with a sufficiently small spacing of values such that one of the diagrams can be selected and applied with reasonable accuracy to a specific problem. For some specific gap width it may be desirable to obtain the diffraction pattern by interpolation between two diagrams; however, the accuracy with which the design wave data are known usually does not justify such a refinement. In the event though that interpolation is desired, Figs. 7-10 are provided which show values of diffraction coefficients for various gap widths at various x/L distances from the gap center line and at various y/L distances to the lee of the gap. These curves have been smoothed somewhat to eliminate the unimportant lobes which result from the theoretical solutions as shown in Figs. 4-6. It is to be noted that in Figs. 4-6, inclusive, the diffraction diagrams have been terminated arbitrarily at a distance of 20 wave lengths in the lee of a gap. It is believed that in most applications the effects of refraction, as discussed above, would predominate by the time the waves had traveled a distance of 20 wave lengths beyond a breakwater; therefore, the extension of the diffraction patterns to greater distances is unnecessary.

When a gap width is in excess of about five wave lengths, the diffraction patterns at each side of the opening are more or less independent of each other (compare Figs. 3 and 6b). In such cases the pattern given by Fig. 3 for a semi-infinite breakwater can be used to estimate the height and direction of waves on the leeward side as discussed by Dunham (1951) and illustrated in Fig. 2b. For these relatively large gap openings the direction of the incident waves with respect to the breakwater alignment can lie anywhere within the zone indicated in Fig. 3 without the diffraction pattern being appreciably affected. For relatively narrow gaps (gap openings of about 3 wave lengths and less) the diffraction pattern can be computed easily by the method of Carr and Stelzriede (1951) for various values of the angle between the incident wave and the breakwater. As an example, Figs. 12-14 show diffraction patterns for waves approaching a breakwater gap with a width of one wave length from various directions.



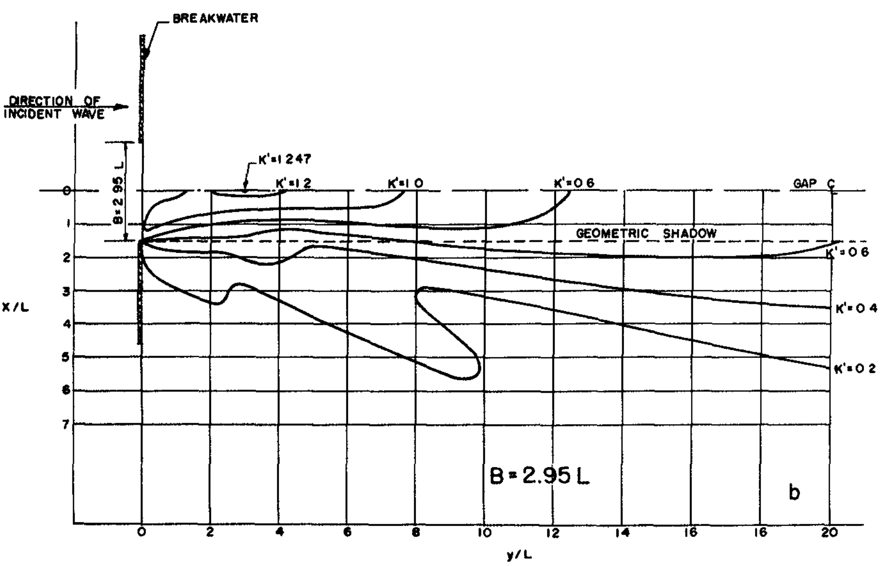
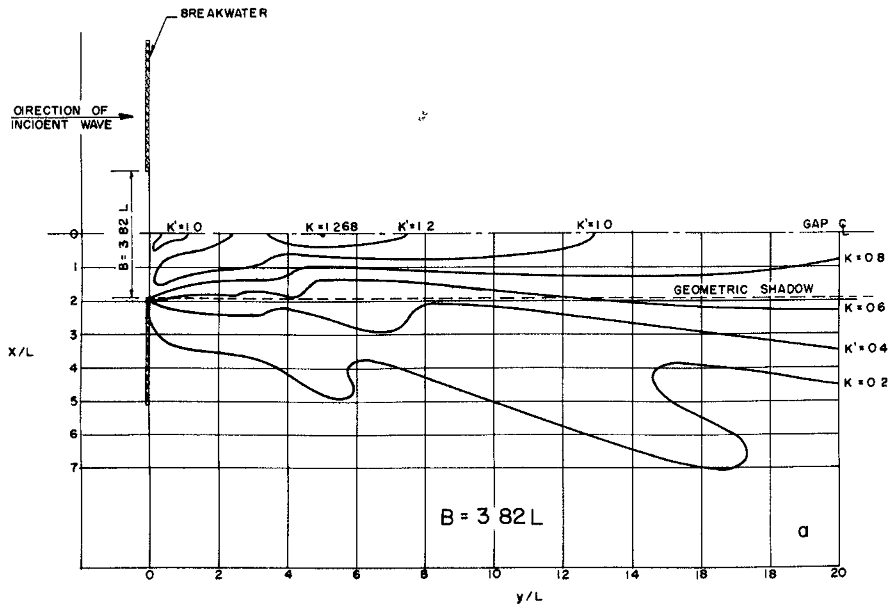


Fig. 5
Generalized diagrams for diffraction at breakwater gaps of two and approximately three wave lengths in width (90 degree approach).



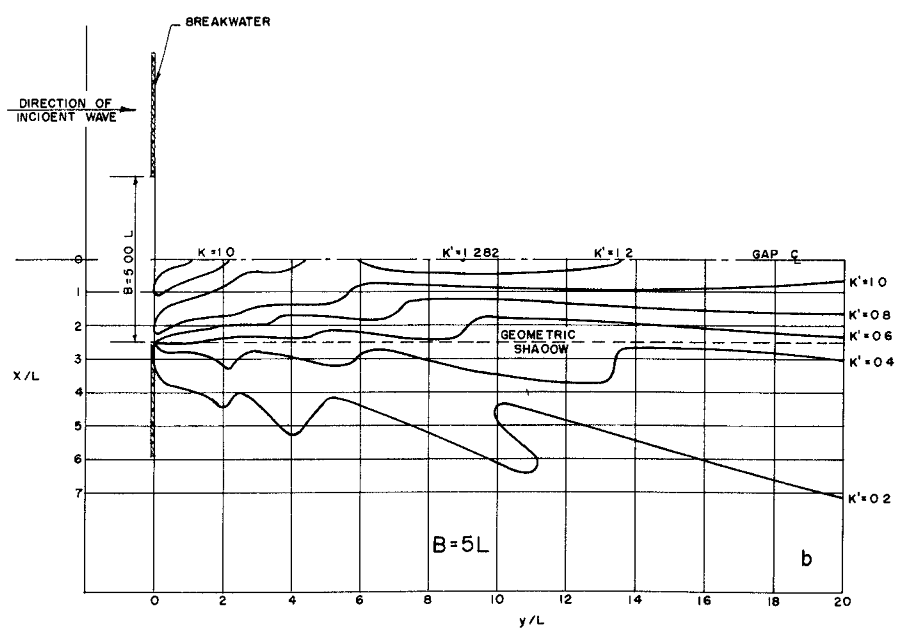


Fig. 6
Generalized diagrams for diffraction at breakwater gaps of five and approximately four wave lengths in width (90 degree approach).

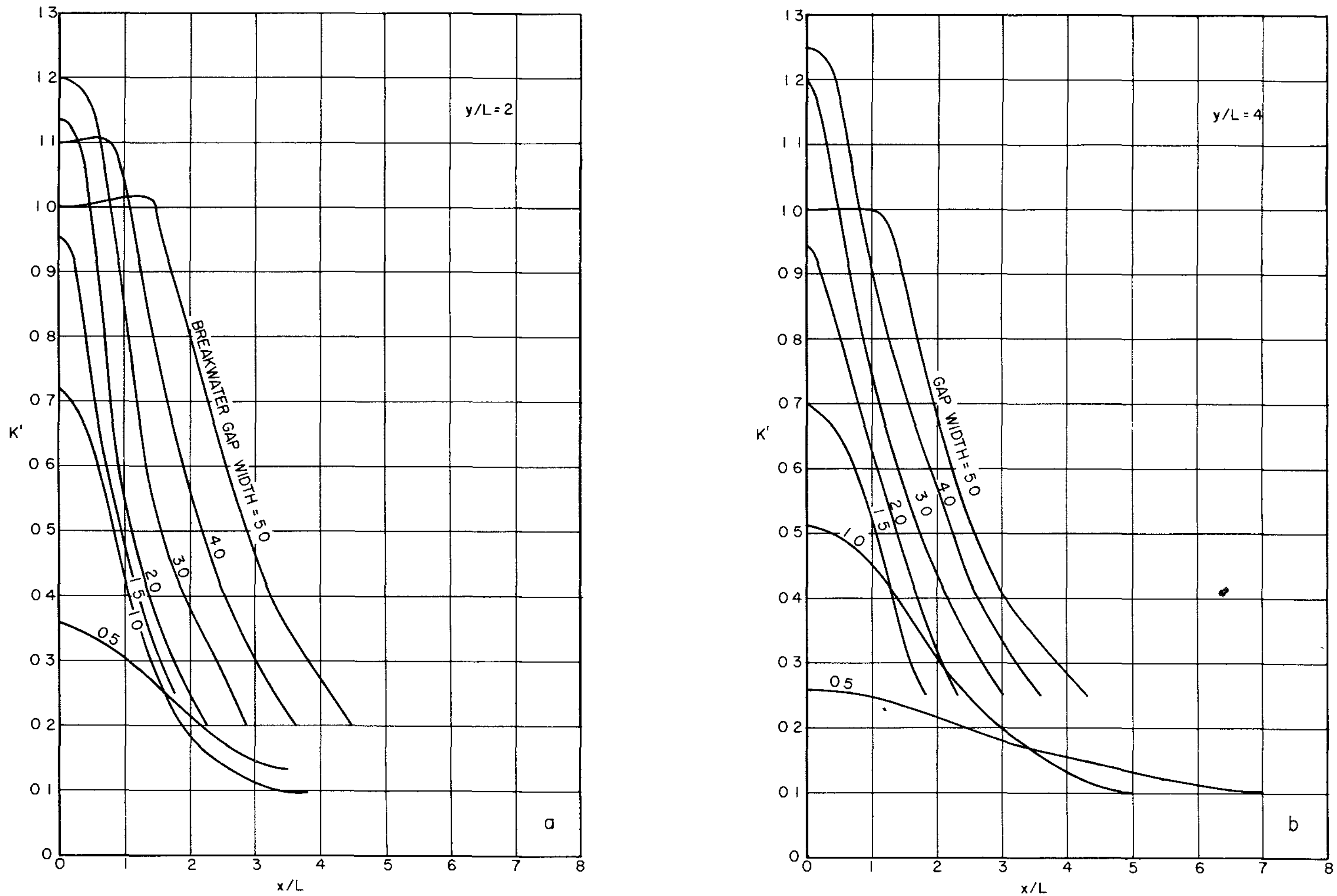


Fig. 7 Diffraction coefficients at various points in the lee of breakwater gaps of from one-half to five wave lengths in width (90 degree wave approach).

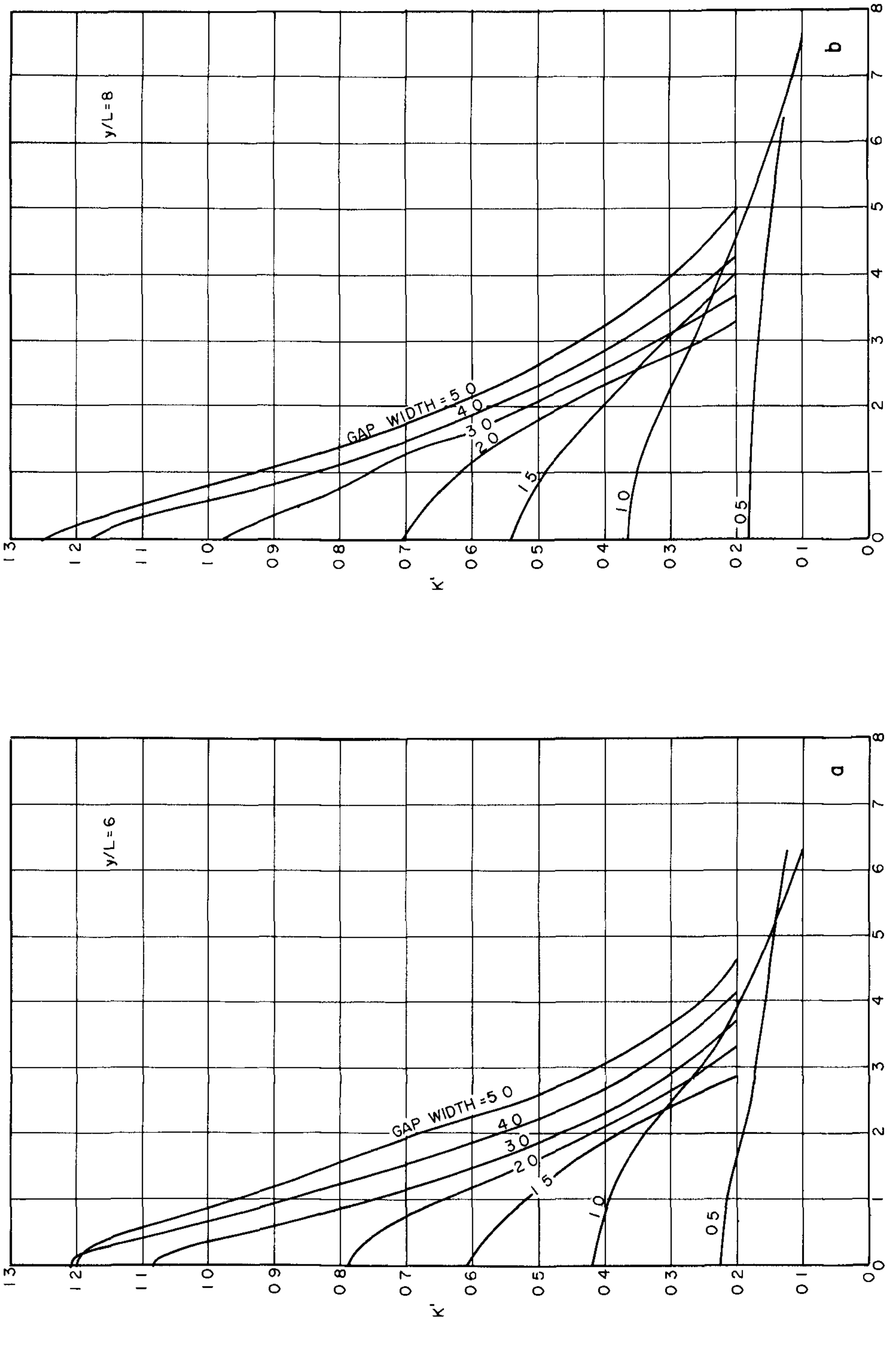


Fig. 8 Diffraction coefficients at various points in the lee of breakwater gaps of from one-half to five wave lengths in width (90 degree wave approach).

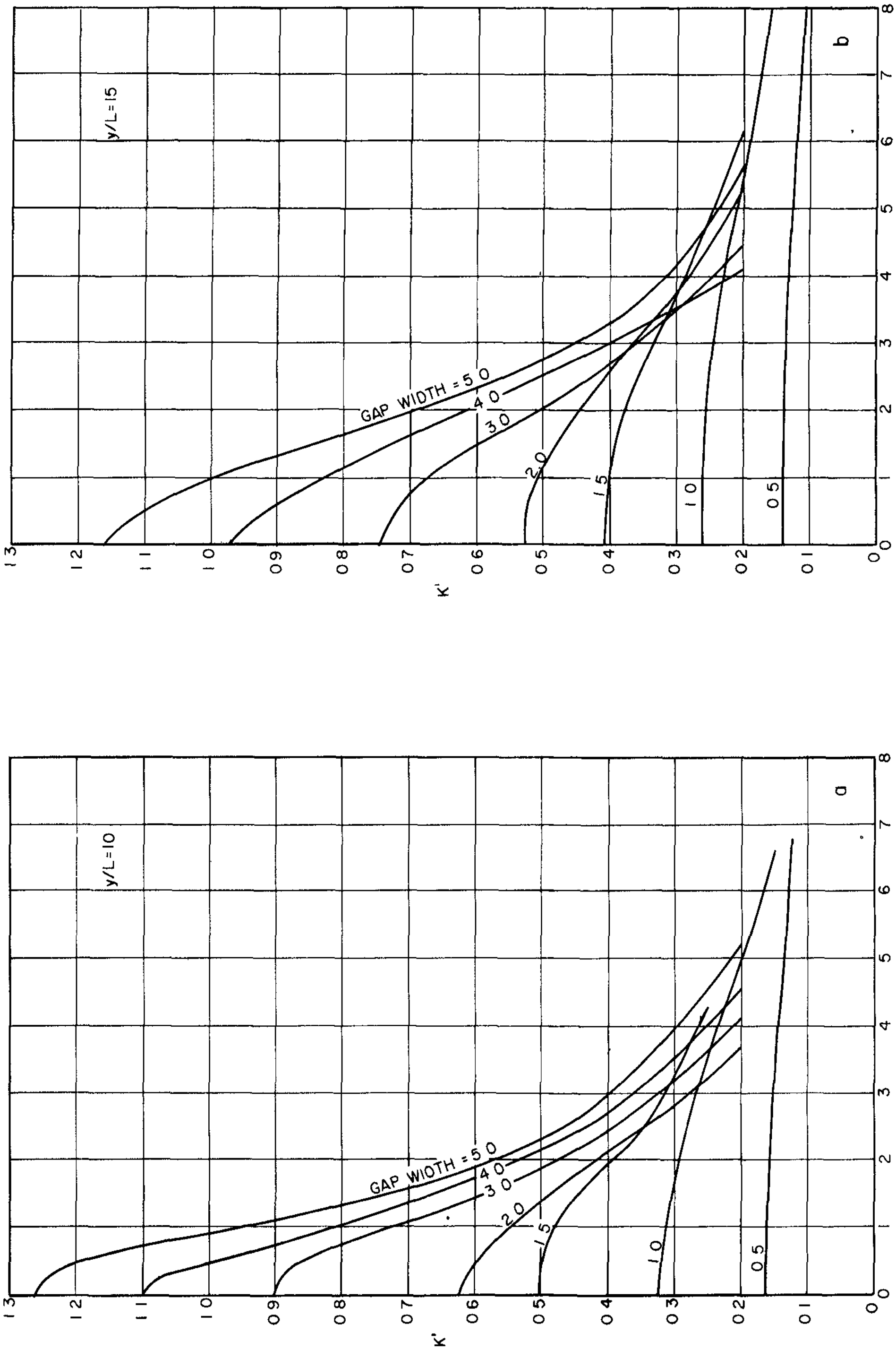


Fig. 9 Diffraction coefficients at various points in the lee of breakwater gaps of from one-half to five wave lengths in width (90 degree wave approach).

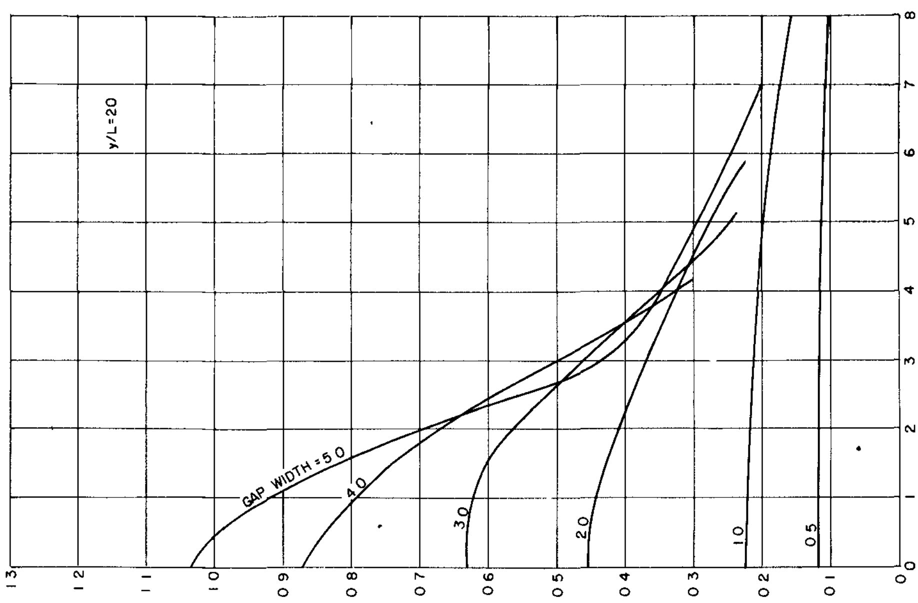


Fig. 10 Diffraction coefficients at various points in the lee of breakwater gaps of from one-half to five wave lengths in width (90 deg. wave approach).

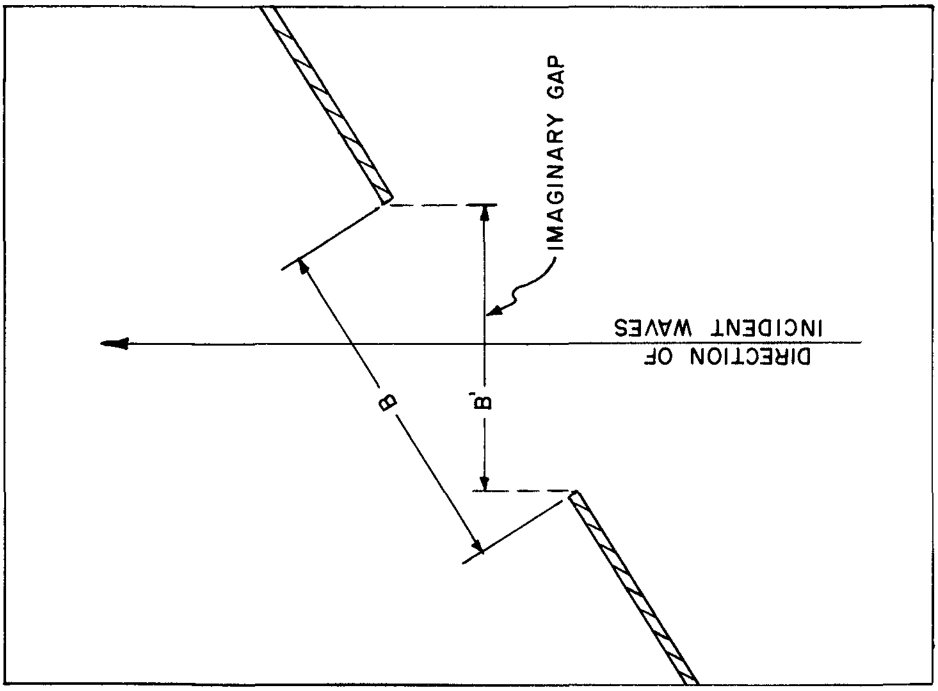


Fig. 11

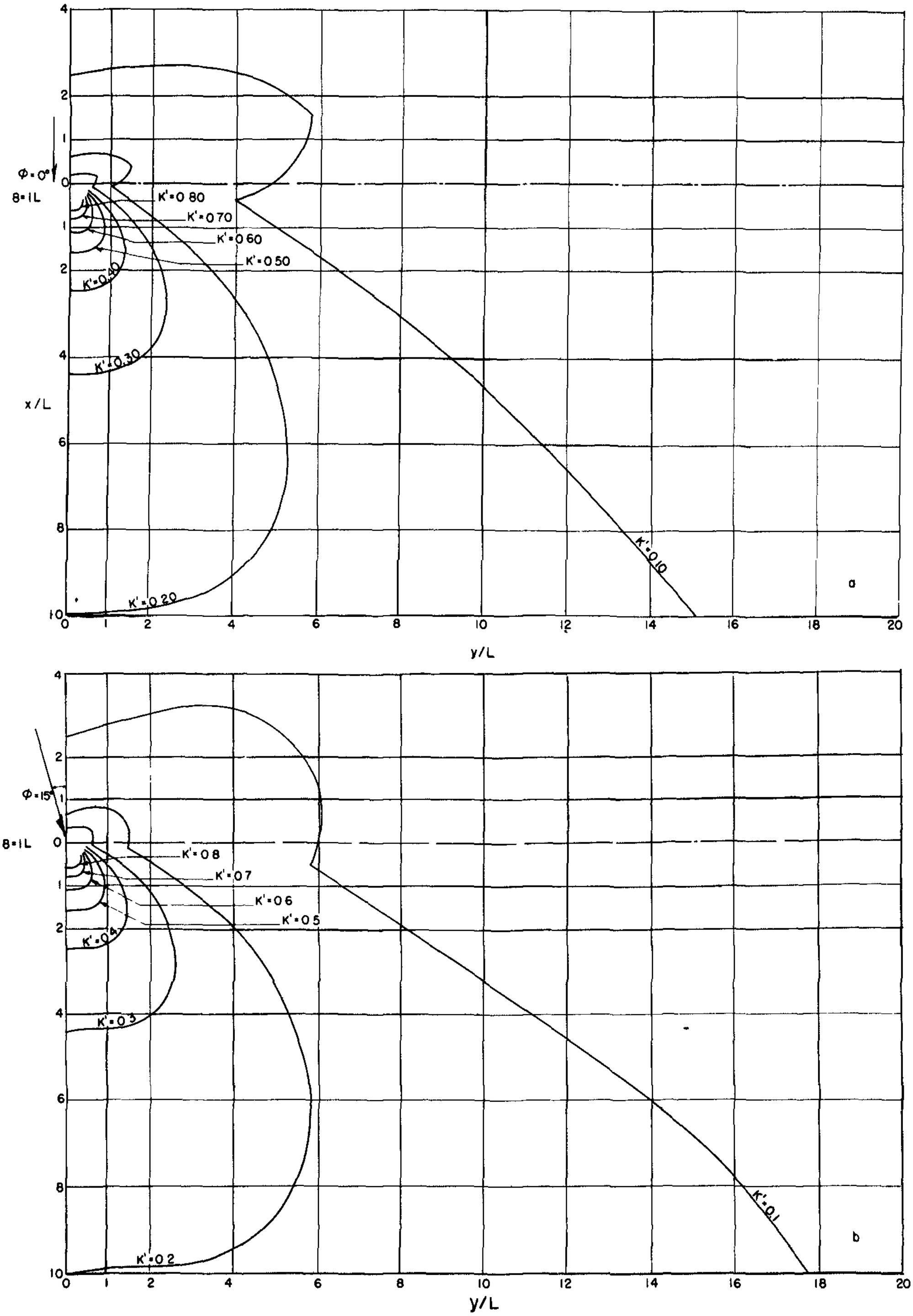
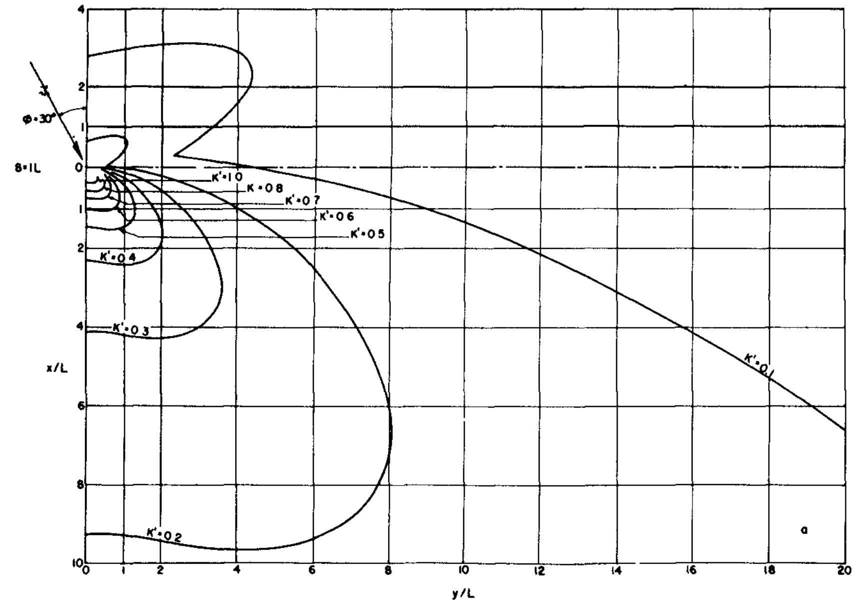


Fig. 12
Generalized diagrams for diffraction at a breakwater gap of one wave length width (ϕ = 0 and 15 degrees).



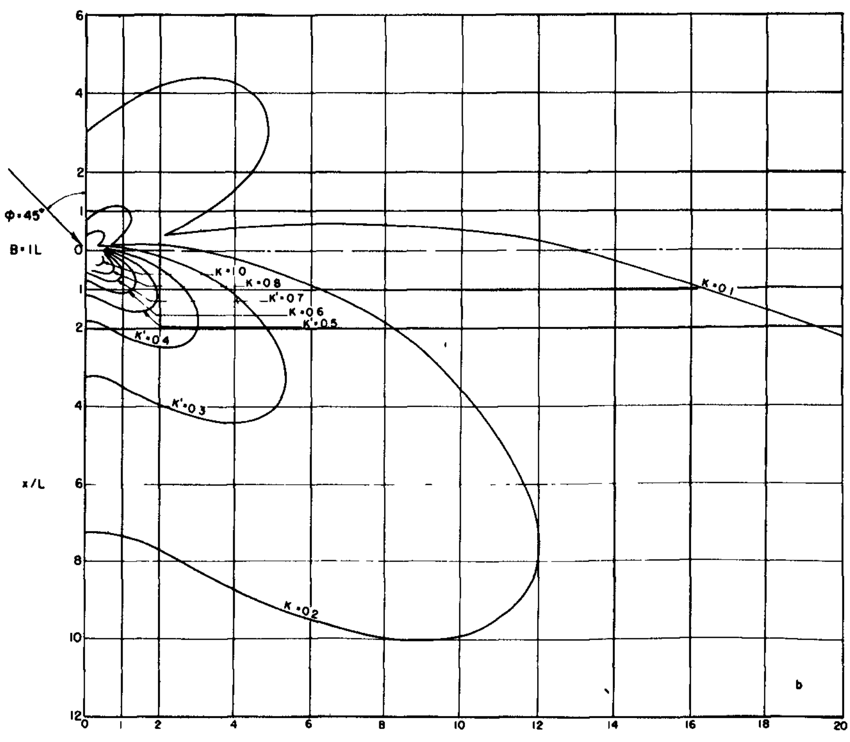


Fig. 13
Generalized diagrams for diffraction at a breakwater gap of one wave length width (Ø = 30 and 45 degrees).

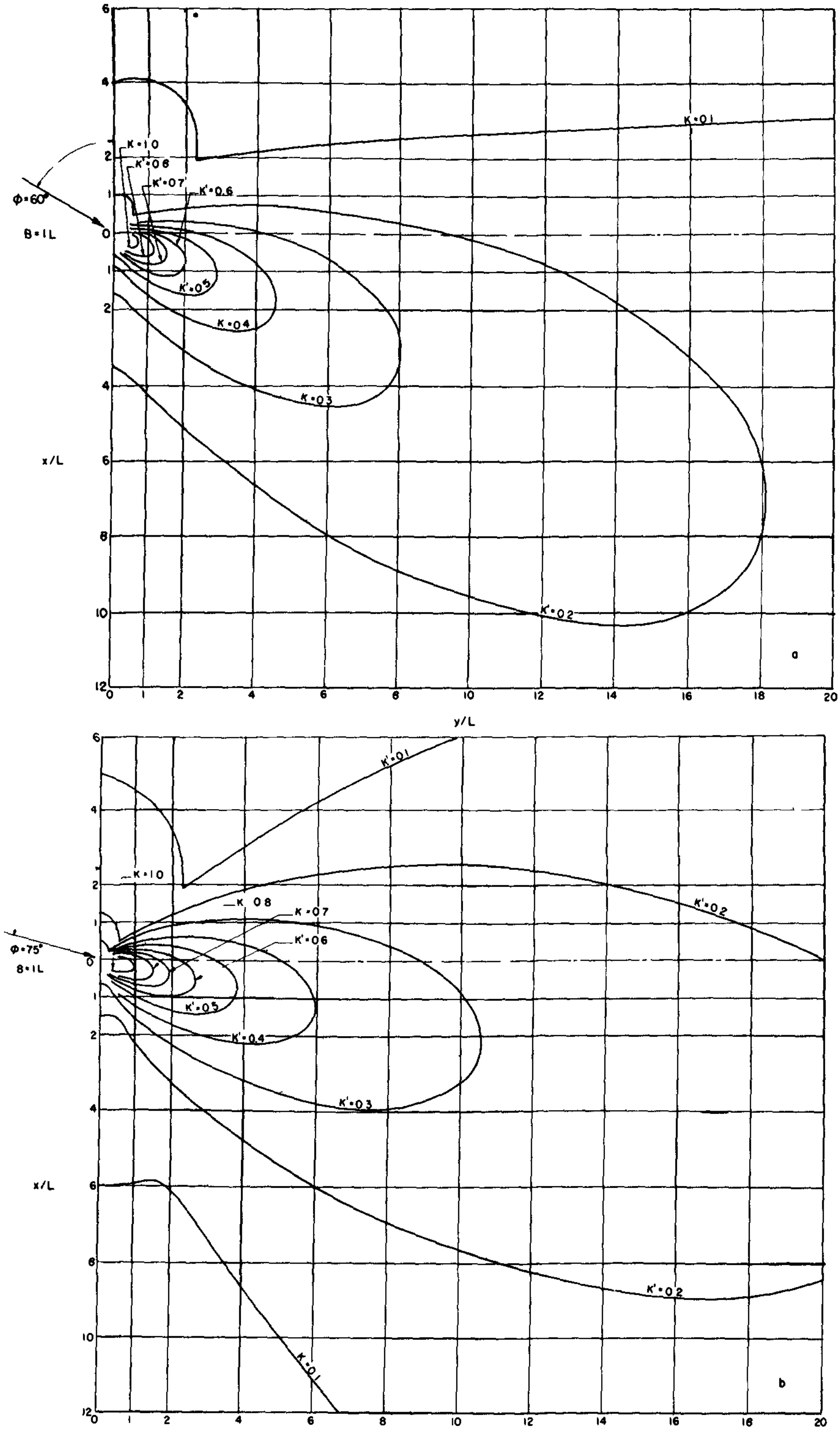


Fig. 14 Generalized diagrams for diffraction at a breakwater gap of one wave length width (Ø = 60 and 75 degrees).

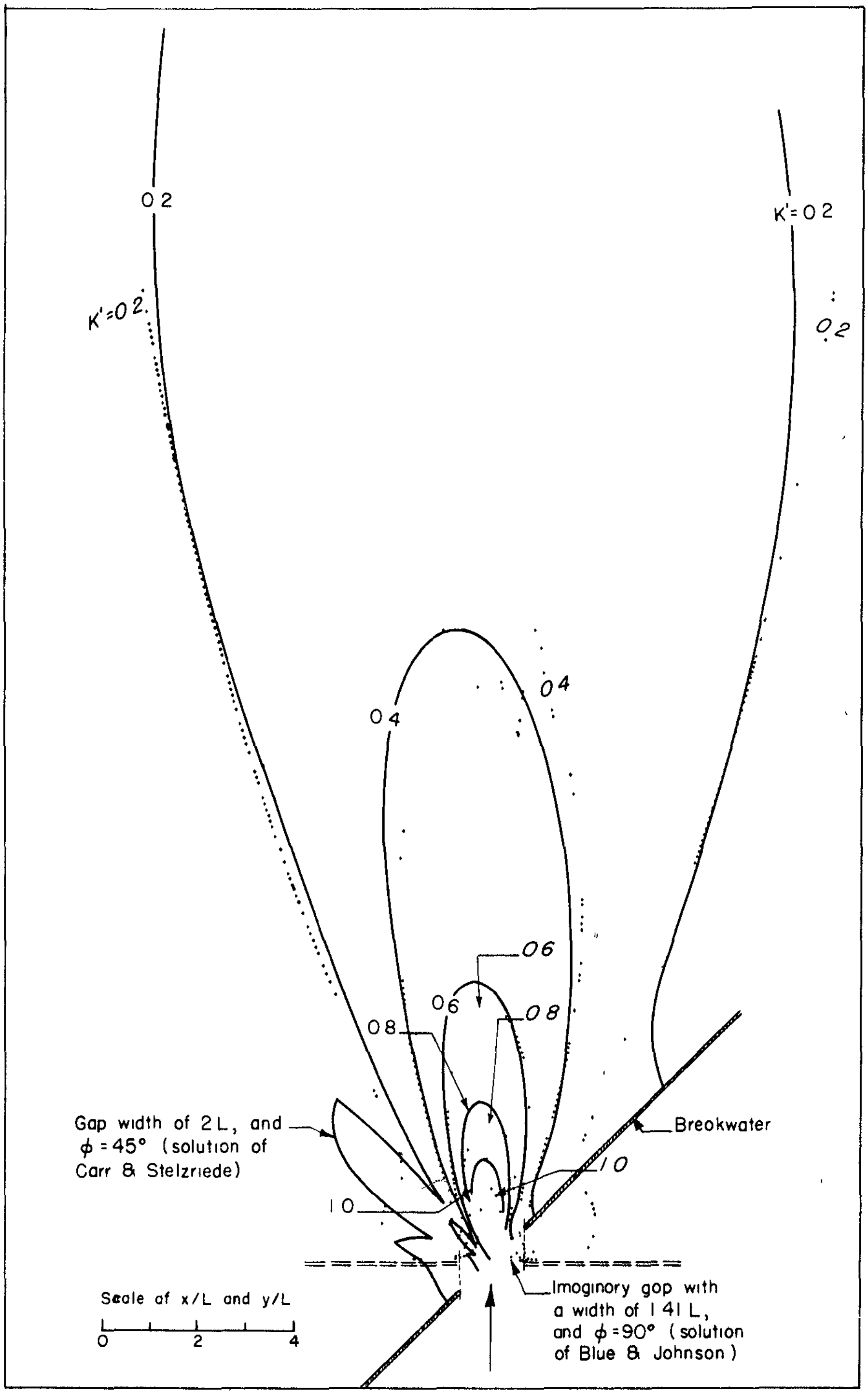


Fig. 15 Generalized diffraction diagram for a gap of two wave lengths and a 45 degree approach compared with that for a gap of width $\sqrt{2}$ wave lengths with a 90 degree approach.

For wider gap openings, where oblique approaches make computations of diffraction patterns relatively difficult, useful approximations can be made by drawling a line through the gap center and normal to the incident wave direction, and then computing diffraction coefficients as though the breakwater were along this line--the end of the imaginary gap being at the projections on this line of the true gap ends (Fig. 11). That this approximation gives acceptable results is demonstrated in Fig. 15 where the diffraction diagrams computed for a gap opening of 2 wave lengths with a wave approach of 45 degrees is compared with a diagram which has been computed for a 90 degree approach to a gap whose width of opening is 1.41 wave lengths. For a given gap opening with an oblique wave approach the width of an imaginary gap for 90 degree approach undoubtedly will be an uneven value. The preparation of a diffraction diagram for such a gap opening is easily accomplished by interpolation from the diagrams shown in Figs. 7-10, inclusive.

SUMMARY

The material summarized in this paper presents generalized diffraction diagrams to be used in the rapid solution of wave diffraction problems which occur in breakwater design. The diagrams are to be used in conjunction with the techniques of application previously described by Dunham (1951).

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