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INTERACTION OF A SURFACE WAVE WITH A CRACK IN A CONCAVE HALF SPACE

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UDC 539.3.534.231.1

The interaction of a Rayleigh wave with a stationary crack in a rectilinear surface was treated in [1, 2]. It was shown that under certain conditions a surface wave can generate dynamic stresses large enough to extend a crack. However, there have been no studies of the interaction of a surface wave with a crack in a curvilinear half space, although this case is encountered more frequently in practice. We use the method of dynamic photoelasticity to observe the interaction of a surface wave with an edge crack along and normal to a concave half space. The research was performed on 350 × 400 × 15-mm samples of polymethyl methacrylate. A surface wave of duration up to 50 μsec was excited by a point microexplosion on the linear portion of the sample joined with the curvilinear part. The interaction of the surface wave with a crack was recorded in circularly polarized light by an SFR-1 high-speed motion-picture camera at $1.5 \cdot 10^6$ frames/sec.

We first considered the propagation of a surface wave along a concave half space without a crack, and then its interaction with a crack. The film strips in Fig. 1 illustrate the propagation of a surface wave along a concave half space of constant radius of curvature R = 50 mm. They show that in the propagation of a Rayleigh wave along a rectilinear half space the stress distribution in the wave has a complex shape: There are three stress rosettes, two of which are located directly on the surface of the half space in front of and behind the main disturbance. When a wave moves in a curvilinear half space there is a continuous redistribution of elastic energy in the surface wave. In the $0 < \alpha < 90°$ part, where α is the central angle, there is first observed the development and strengthening of the surface rosette in front of the main disturbance as a result of a partial weakening of the last and second surface rosettes, and then the transformation of the main disturbance into a body wave traveling with the velocity of a transverse wave. It should be noted that independently of the radius of curvature (R = 10, 25, 50, and 75 mm) the transformation of the surface wave into a transverse wave occurs at $\alpha = 90°$. The strain measurement of dynamic stresses in the rectilinear portion of the half space produced by a surface wave shows approximately identical duration of the compression and tension phases in the Rayleigh pulse (Fig. 2a), i.e., $T_c = T_t = 0.5T$, and the amplitudes of the compressive and tensile stress components are in the ratio 1 : 1.5. Figure 2b-e shows oscillograms of the surface stresses and the corresponding film strips of the distribution of maximum tangential stresses in the wave in passing through the $\alpha = 45$, 90,

Kharkov. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 137-143, May-June, 1979. Original article submitted April 3, 1978.

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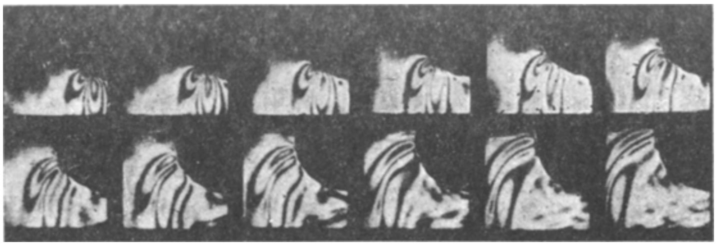

Fig. 1

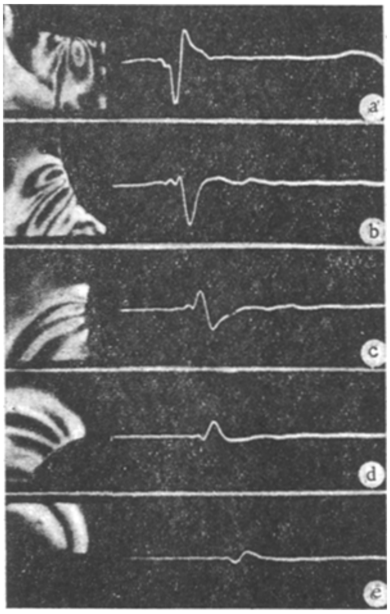

Fig. 2

135, and 180° parts. The oscillograms were obtained for various sweep times. They show that during the motion of a wave in the $0 < \alpha < 45°$ part the amplitude of the compressive stress is decreased, and at $\alpha = 45°$ there are practically only tensile stresses in the surface wave. This clearly demonstrates the pattern of the distribution of maximum tangential stresses. During the subsequent motion of the wave a component of compressive stress appears in front of the tension phase. When $\alpha = 90°$ a stress corresponding in shape to a Rayleigh wave but with a change in the order of the compression and tension phases appears on the surface; i.e. if earlier there were tensile stresses in front of the running rosette, there are now compressive stresses. In this case the ratio of tensile and compressive stress components remained as before, and the duration $T_c = 0.5\ T_t$.

In the $90° < \alpha < 135°$ part there is again a redistribution of elastic energy, and as a result for $\alpha = 135°$ the surface wave contains only the compression phase. Later, for $135° < \alpha < 180°$, there is an opposite distribution of elastic energy, and at $\alpha = 180°$ the distribution of stresses on the curvilinear surface corresponds completely to the Rayleigh wave with the same duration of phases $T_t = T_c = 0.25T$.

The changes of stresses in the surface wave noted above occur as a result of a change of the plane of the half space with respect to the direction of propagation of the wave.

It is of interest to consider the interaction of such a wave with a crack on a concave surface. Taking account of the fact that in the $0 < \alpha < 90°$ and $90° < \alpha < 180°$ parts the wave undergoes approximately the same changes, only two cases were considered: cracks at $\alpha = 45$ and 90°, i.e. at those points where strain measurements of the dynamic stresses were performed earlier. For $\alpha = 45°$ and a crack along the normal to the half space, the process of its interaction with a surface wave includes the phenomena of diffraction, reflection, and the transformation of the surface wave into a body wave. The film strips illustrating these phenomena are shown in Fig. 3; in a–c the cracks are in the $\alpha = 45°$ part and have depths of 5, 10, and 15 mm, respectively; in d the crack is 10 mm long and is located in the $\alpha = 90°$ part. The effect of crack depth on the interaction with a surface wave is clearly shown. It can be seen from the film strips that for a crack 5 mm deep the

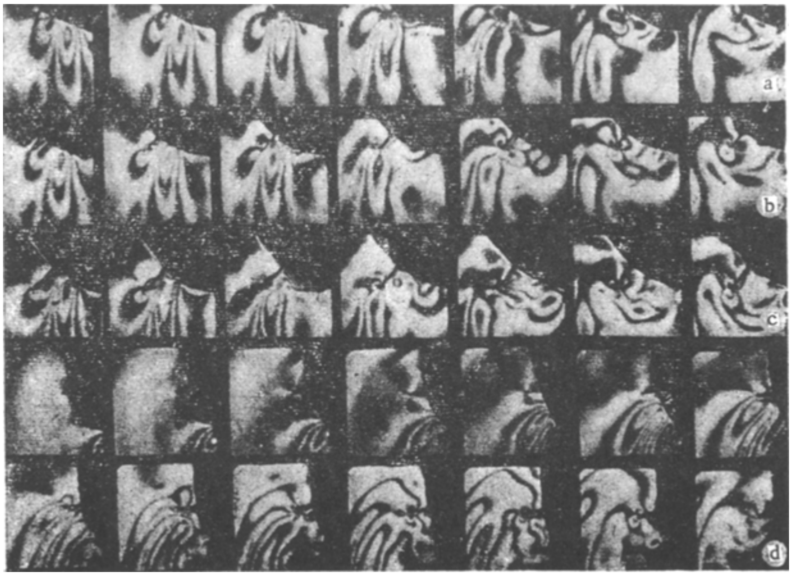

Fig. 3

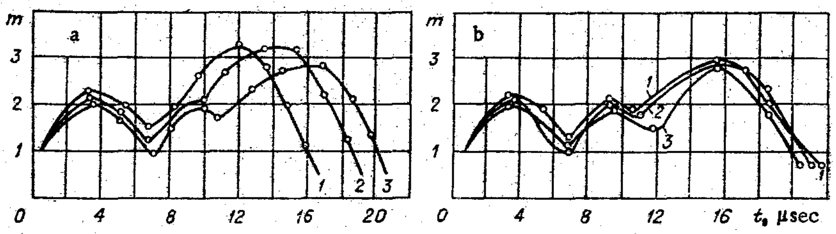

Fig. 4

dynamic stresses at its tip first increase as a result of the interaction of the surface stress rosette in front of the main disturbance. In the stress field formed the distribution approaches the pattern which results from the effect of a longitudinal wave propagating along one edge of a crack [3]. The tangential stress gradient is the same as that resulting from the action of a longitudinal wave traveling at an angle of 80-85° with the direction of the crack.

As the main disturbance leaves the tip of the crack it does not cause an appreciable increase in stress. It easily slips along the crack and then is broken off from the tip and is transformed into a transverse wave. There is a significant increase in stress at the mouth of the crack immediately after the departure of the main disturbance. In this case the gradient of the maximum tangential stress lies along the extension of the crack. This means that negligible expenditures of energy are required to stimulate the growth of the crack. Such a stress field arises at the tip of a crack under the action of a Rayleigh wave [4]. However, in this case the crack is too small to be observable.

The increase in length of a crack (l = 10, 15 mm) does not cause an appreciable increase in stress, but produces certain changes in the interaction of a wave with a crack: The reflection of the main disturbance is strengthened, there is a time separation of the effect on the crack of the surface rosette, the main disturbance, and the Rayleigh wave produced at one edge of the crack by the diffraction of the main disturbance at the dihedral angle formed by the plane of the crack and the free half space (Fig. 3c).

An interesting peculiarity is the fact that in the case under consideration the crack turns out to be oriented along a surface rosette, and as a result this disturbance leaves the crack without diffraction at the dihedral angle. From an analysis of the stress field produced at the tip of the crack it can be concluded that displacements in the stress rosette itself are also directed along the crack. As a result of this the dynamic stresses in the present case are larger than those resulting from the action of a Rayleigh wave on a crack lying along the normal to a rectilinear half space [2]. Consequently, under strictly similar conditions the curvature of a half space increases the dynamic stresses at the tip of the crack.

Fig. 5

The cracks under consideration lie at a certain angle with respect to the main disturbance, which leads to the simultaneous diffraction of the main disturbance at the dihedral angle and at the tip of the crack. Diffraction at the dihedral angle is accompanied by the excitation of surface waves at its edges and diffraction at the tip of the crack, producing negligible stresses in its neighborhood, and transforms the main disturbance into a transverse wave. Thus, the energy of the main disturbance is divided into three parts: The first is reflected in the form of a surface wave, the second is radiated into the volume by a transverse wave, and the third moves toward the tip in the form of a Rayleigh wave. The departure of the Rayleigh wave from the tip increases the dynamic stresses whose distribution is characteristic of this type of wave. Curves 1-3 of Fig. 4a correspond to crack lengths $l = 5$, 10, and 15 mm and a radius of curvature $R = 50$ mm. The curves show the time dependence of the stress concentration for cracks of various depths, from which it is clear that an increase in crack size does not lead to an increase in stress, but increases the time of the interaction of the wave with the crack and causes additional stress fluctuations at its tip. It should be noted that an increase in crack size also decreases the effect of the curvature of the half space on the interaction of the wave with the crack and the formation of dynamic stresses at its tip, since as the wave leaves the rectilinear surface of the crack it is transformed into a Rayleigh wave.

The pattern of the interaction of a surface wave with a crack in the $\alpha = 90°$ part is very noteworthy. The wave emerges into this region of the half space attenuated by approximately a factor of two as a result of the transformation of the main disturbance into a transverse wave. By itself the separation of a transverse wave hardly affects the shaping of the stressed state at the mouth of the crack. The dynamic stresses produce a new surface wave with a changed polarity of the compression and tension phases in the surface rosettes. The departure of the first surface rosette also is not accompanied by an increase in stress, or if there is an increase it is too small to be recorded by the method chosen. The emergence of the main disturbance leads to the formation of stresses characteristic for shear deformation along the crack; i.e. the conditions are such that the crack and the displacements in the main disturbance are in the same direction. After the diffraction of the main disturbance by the tip of the crack a stress rosette is formed in its neighborhood which is characteristic for separation deformation, and as a result a "stress knife" is produced in front of the crack tip. A pattern of this kind is produced in the motion of a crack with a velocity close to the Rayleigh velocity, or in the simultaneous action of two Rayleigh waves propagating along both edges of a crack [2]. Probably the action of the wave under investigation leads to the excitation of Rayleigh waves at the tip of the crack propagating from the tip of the crack and thus produces the stress pattern recorded; i.e., in the present case the inverse problem is realized. There is no doubt that when the stress concentration becomes sufficient for crack growth this growth will proceed very rapidly. The film strips obtained establish another characteristic: The diffraction of a wave leads to the repeated transformation of a surface wave into a transverse wave propagating at an angle of 90° with the direction of motion of the first transverse wave.

In order to eliminate the effect of the dihedral angle on the processes under study, cracks were considered oriented along a concave half space. The film strips illustrating this case are presented in Fig. 5. They show that in the diffraction process only surface stress rosettes are involved, and after the wave leaves the tip of the crack the main disturbance is completely transformed into a transverse wave.

In the $\alpha = 45°$ part the diffraction of the wave produces dynamic stresses at the tip of the crack which are characteristic for the effect of a longitudinal wave incident at a certain angle with the plane of the crack. The magnitude of the dynamic stress turns out to be negligible. On this basis it can be concluded that in the process of shaping the dynamic stress field at the tip of a crack only a negligible fraction of the elastic energy carried by the surface wave takes part, namely that part which gives rise to displacements of particles of the medium directed at a certain angle with the plane of the crack. The process of shaping the stress field at the tip of a crack is accompanied by intense radiation of elastic waves. This can be traced by the diverging isochromatic curves and indicates the attenuation of the diffracted wave. It is noted that elastic energy is radiated into the volume twice with a certain separation in time: as a result of the diffraction of the surface rosette and the separation of the main disturbance.

Fig. 6

For a crack in the $\alpha = 90°$ portion, in spite of appreciable attenuation of the wave (approximately by a factor of two), the dynamic stress produced at its tip is larger than in the case considered above. This results from the change of the front of the surface wave and the creation of conditions for which the displacement of particles at the front of the propagating wave is directed at a small angle with the plane of the crack. An interesting feature is the fact that in this portion the curvatures result in a change of phase of the surface wave, and the stress field produced at the mouth of the crack is due to the action of the tension phase.

A general characteristic of all the cases considered is the change of the wave front and the distribution of maximum tangential stresses in the wave as the result of diffraction. The complex stress pattern results from the formation of several types of waves propagating with different velocities and having their own characteristics of interaction with a crack. Therefore, at the tip of a crack there is a continuous variation of stress in time and space. In addition, in all the cases considered a variation of the radius of curvature of the half space between $R = 10$ and 75 mm does not produce a significant change in the interaction of the wave with a crack (cf. Fig. 4b; curves 1-3 correspond to $R = 25$, 50, 75 mm for $l = 15$ mm).

An increase in intensity of the surface wave leads to crack growth (Fig. 6). In this case the growth occurs under the influence of the tension phase or as the result of the shaping of the stress field producing tensile stresses at the tip of the crack.

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