KERALA AGRICULTURAL UNIVERSITY

COLLEGE OF FISHERIES

REPORT OF THE PROJECT

STUDIES ON WAVE REFRACTION ALONG SHORELINE NEAR COCHIN

(F. PGD. - F . H . 7 / 90)

By

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SUMMARY

Wave refraction along the coastline near Kochi has been studied using computer programme. Depth data at grid points for use as input have been digitised from hydrographical charts by drawing additional depth contours. After trial runs, data from area 9°38′to 10°51′N latitude and 75°37′ to 76°20′E longitude have been used. Wave periods 5,6,7,8and 9 seconds and directions 240°, 270° and 300° have been made use of as these are found to be the most frequently occurring waves.

Wave refraction diagrams have been prepared and possible regions of erosion and accretion have been identified. It is seen that the shore line north of Cochin bar mouth is more disturbed by the wave refraction. During southwest monsoon period, erosion is seen around Malippuram and Pallippuram while deposition is possible at Narakkal. Mild erosion is seen at Azhikkal during fair weather season. Zones of rip currents, seen around Malippuram and Narakkal may have implications in the formation of mudbanks (Chakara) off Vypin and off Narakkal.

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INTRODUCTION

The shorelines are always in a state of dynamic equilibrium with the sediments moving onshore and offshore and also along the shore in one direction or other. For planning constructions on the beach for development and tourism, for establishing a harbour etc., the knowledge of wave transformation at the particular shoreline is very essential. Waves moving towards shoaling water at an angle to the bottom contours, change their direction of progress and become parallel or almost parallel to the shore before breaking. This process is known as wave refraction.

Wave refraction is caused by the dependence of wave speed upon water depth, in the regions where water depth is less than half the wavelength. For the refraction of waves in shallow waters, Snell's law of refraction in optics is applicable.

$$\mathrm{Sin}\, A_1 / \mathrm{Sin}\, A_2 = C_1 / C_2$$

where, A_1 and A_2 are the angles between adjacent wave front positions and adjacent bottom contours, and C_1 and C_2 are the wave velocities at these locations. The assumption that the Snell's law can be used to describe the refraction of water gravity waves has been shown to be mathematically proper for linear wave theory in shallow water.

Before the waves reach the coast, they travel over shoaling waters where these are influenced by the submarine relief. The effect of wave refraction must be taken into account for ascertaining the impact of wave action on the coast. Because of the variation in topography, wave refraction in each shallow area must be studied separately. Similarly, refraction of waves of different periods and different directions of approach must be studied separately.

Wave refraction in relation to coastal erosion along a part of the Kerala coast extending from Thottappally to Cochin was studied by Varma (1971). Reddy and Varadachari (1972) studied the movement of sediments along the West Coast of India from Cape Comarin to Goa using wave refraction diagrams and identified areas of erosion and accretion. With the help of wave refraction diagrams for waves having periods 4,6,8,10 and 12 seconds and approaching from 200°, 220°, 240°, 260°, 280° and 300°, Varma and Varadachari (1977) studied the stability of the coastline from Manakkodam to Thottapally. Das *et.al.* (1966) described wave refraction pattern near Cochin by graphical method.

With the help of refraction diagrams for waves of different periods approaching the shore, between Anthakaranazhi and Azhikode from different directions Shenoi and Prasannakumar (1982) observed that, in general, waves from 220° and 240° can cause erosion, while those from 280° and 300° can cause accretion. On the other hand, waves from 260° cause erosion at some places and accretion at some other places. Prasannakumar *et al.* (1983) estimated the volume of littoral sediment transport at 2m depths along the shoreline, between Munambam and Anthakaranazhi for waves with directions ranging between 220° and 300° and with periods ranging from 6 to 14 seconds. Shenoi (1984) studied wave refraction diagrams in relation to stability of the beaches. Prasannakumar (1985) investigated the sediment transport in the surf zone along the beaches near Cochin. Recently, Pillai (1998) applied computer programme for studying wave refraction in this area and observed general agreement in wave energy convergence and divergence, obtained by computer method and those in earlier studies by graphical method.

Wave refraction diagrams:

Wave refraction analysis is based on the following assumptions (US Army, 1977):

a) Wave energy remains constant between wave rays.
b) Directions of wave advance are perpendicular to the wave crests.
c) In shallow water, the speed of a wave of given period depends only on the depth at that location.
d) Changes in bottom topography are gradual.
e) Waves have long crests, constant period, and small amplitude and are monochromatic.
f) Effects of currents, winds and reflection from beaches and underwater topographic variations are negligible.

Graphical method:

For constructing wave refraction diagrams, the bathymetric chart of the area under study is required. The chart should extend from the shoreline up to a depth of at least half the wavelength of the longest wave to be studied. Depth contours are drawn on the map. Graphical method for drawing wave refraction diagrams manually is by using a template. Successive positions of wave ray as it advances from deep water towards the shore are obtained manually. These positions are joined by a smooth curve to take one ray up to the coastline. Several such wave rays have to be drawn for waves of each period approaching from different directions. As can be seen, this is a very cumbersome and time-consuming process.

Computer method :

Because of the development of computer programmes, the construction of wave refraction diagrams has become comparatively simple. Initial position and characteristics of wave are given as input and subsequent path of wave ray is computed using wave celerity on a grid of water depths. Wilson (1966) used a linear surface for local sea bottom for calculating water depth at positions between grid points. More realistic quadratic surface has been made use of by Dobson (1967). Coleman and Wright (1971) have incorporated bottom friction into the model. Kurian and Baba (1988) have presented this computer programme with modifications to facilitate to switch to fine meshed inshore depth grid as the wave approaches close to the shore. They have observed high correlation between shallow water wave heights obtained by this computer programme and those by wave measurements.

MATERIALS AND METHODS

Unlike most of the earlier studies in the Cochin area, which were by manual graphical method, in the present study the computer method has been made use of. Computer program developed by Dobson (1967) with some modifications is used (see also Kurian and Baba, 1988). Options for input in feet, miles or metres and subroutine to convert from CGS to [illegible] FPS and vice-versa are avoided in the present model because in the present study all inputs are in metres. Also, the control to stop the ray at breaking point is not considered. In some cases the ray may enter a point on the land close to the shore. This is because depth grid includes arbitrary levels on the land also. Refraction diagrams are, however, limited up to the coastline.

The computer programme consists of a main programme WAVES and six subroutines. The function of the main program and subroutines are given below.

Programme WAVES: This program reads the input data viz. grid parameters, depth grid, co-ordinates of the starting point of wave ray, special matrix for calculating depth etc. After reading the data for the first ray, the control passes to the subroutine RAYCON.

Subroutine RAYCON: This subroutine is for controlling each individual ray as it progresses across the grid. It calculates the second point on the ray assuming that the wave is still in deep water and calls subroutine DEPTH to find the depth at this new point. If the depth is greater than the refraction depth, then the subroutine WRITE is called which prints the wave details at this point. If the wave has reached the shoaling water, the subroutine CURVE is called for calculating the initial value of the ray curvatures.

Subroutine REFRAC: This is for solving the refraction equations iteratively for getting the next point on the progress of the wave.

Subroutine CURVE: This calculates the local speed of the waves and also the curvature of the wave ray.

Subroutine DEPTH: Special matrix provided with the data is used for calculating the depth. This subroutine determines the local origin for the point on the ray and then calculates the local co-ordinates. Before computing the coefficients of the equations for the surface of the best fit, it tests to determine whether the point lies within the same mesh square as the previous point. In case it does, the subroutine calculates the new depth using the new local co-ordinates. Otherwise, it calculates the new coefficients for the surface equation and then finds depth.

Subroutine ERROR: A measure of the error involved in calculating depths by using a least square surface is estimated here.

Subroutine WRITER: This subroutine controls the printed output for the programme according to different final endings of wave rays.

All the above subroutines have been tested and combined. The computer programme is presented in Appendix-I. This Programme has been adapted from Dobson

(1967) and Kurian and Baba (1988). The programme is slightly different from theirs as has been mentioned earlier. However, some of the variables in the "common" statements of the programme, though not necessary, are retained, as these were also keyed in initially.

Area of Study:

The area under investigation is the shoreline around Kochi. While some parts of this coast undergoes erosion and accretion cycles, predominant accretion is seen to take place over the years just north of bar mouth, in the Puthuvyppu region.

Wave Climate:

The monthly meteorological charts of the Indian Ocean (H.M.S.O., 1949) and the Ocean Wave Statistics (Hogben and Lumb, 1967) contain some information on deep-water wave climate over the Arabian Sea. Srivastava *et al.*, (1968) and Srivastava and George (1971) have compiled visual observation on waves over the Arabian Sea. Shenoi (1984) averaged the swell data in the neighbourhood of Cochin for the years 1974 to 1980 and produced monthly percentage frequency of swell periods and monthly percentage occurrence of swell direction and heights.

'Wave statistics of the Arabian Sea' (NPOL, 1978) and 'Swell Atlas for the Arabian Sea and Bay of Bengal' (NIO, 1982) provide information obtained from visual data published in the Indian Daily Weather Reports of the India Meteorological Department.

Wave climate off Kerala is, in general, characterized by high and low wave activities during southwest monsoon season and non-monsoon season respectively. Das et al (1979) have presented swell characteristics over a larger area, for 5° square between 10°-15°N and 70°-75°E. It is seen that during October-May, predominant direction is 330°. Wave directions of 360° and 300° are also noticed during this season. During southwest monsoon season, predominant direction is 270° and next predominance is for 240°. During Oct.-May, 5-10 second period waves occur 80% of the time, the predominant period being 5 seconds. Wave period ranged from 5 to 9 seconds during June- September (about 86% occurrence).

Baba and Joseph (1983) reported the wave climate off Cochin based on wave rider buoy data collected for one year from a region where depth is 15m. During both rough season (May-Oct.) and fair season (Nov.-April), wave period ranged between 3 and 11 seconds. During fair season, 95% of the waves were between 4 and 9 seconds while during rough season 85% were between 5 and 9 seconds. Wave direction varied during both seasons between north westerly and south-westerly. The percentage distribution of directions is given in Table 1.

TABLE 1
Wave directions during different seasons

Direction	Percentage occurrence	
	Rough season	Fair season
North west	47	82
West	29	9
Southwest	24	9

It is seen that there is a general agreement between these two estimates of wave climate. In the present study, wave climate which includes data from deep water regions also, presented by (Das et al, 1979) is considered and refraction diagrams have been drawn for wave periods 4,6,7,8 and 9 seconds coming from 240°, 270° and 300°. Both 360° and 330° are not considered, as these are not likely to affect this coastline.

Method:

Initially an area from 10° 17′ to 9° 40′ N lat and 76° 15′ to 75° 40′ E long. was divided into grids with a width of 1.8 km. Depths at grid points have been taken from hydrographic charts after drawing additional depth contours. The hydrographic chart for the region Ponnani to Alleppey corrected up to 1971 was used. The depth values at 38 x 36 grid points were noted. These values were stored in computer after checking errors. Two wave rays each for above five periods and for three directions were run to find out whether the along shore extent of the girds is adequate to get sufficient number of refracted wave rays in the area around Kochi.

Using the results, graphs were plotted manually for periods 5 sec, 6 sec, 7 sec, 8 sec and 9 sec for direction 240°, 270°, and 300° to see whether enough number of rays would come in the region. Since digitised depth data was found to be inadequate, the region for depth grids has been enlarged. The limits of the extended region is from 9°38′ to 10°51′N lat. and 75°37′ to 76°20′E long. Square grids and additional depth contours were drawn and corresponding depths were found at all grid points. Depth values at 74 x 44 grid points were tabulated and stored in the computer. The coordinates of the initial points of all the rays were calculated and entered to the file, which already contained the tabulated depth values. Computer programme has been run using this enlarged depth grid. Wave refraction diagrams have been prepared by using computer plotting of successive X and Y values for each wave ray. Sample data is presented in Appendix –II and the sample output is presented in Appendix –III.

RESULTS AND DISCUSSION

Wave refraction diagrams for above mentioned periods and directions are presented in fig 1(a,b,c), 2(a,b,c) and 3(a,b,c). Convergence and divergence of wave rays are indicators of accumulation and dissipation of wave energy respectively. Depending on the initial wave conditions, the angle of incidence near the shore changes from place to place.

Waves approaching from 240° converge in Malippuram. The intensity of this increases with increase in wave period. Areas of divergence are seen just south, in the shoals (Puthuvyppu and Azhikkal) and just north at Narakkal. For higher period waves, another convergence zone, albeit with lesser intensity, is seen to develop between Narakkal and Kuzhippily. For 9 sec. waves convergence is seen near Kuzhippilly also. Divergence is generally seen around Pallippuram.

Waves from 270°, in general, shows convergence and divergence north of Cochin bar mouth. This feature becomes more and more intense for higher period waves. Around Malippuram, just north of the shoal, is a region of convergence. Another zone is near Pallippuram. In between these two regions, divergence is seen (i.e. near Kuzhippilly). For higher periods (7-9 sec.) divergence is seen around Narakkal also. It is interesting to note that the extent of divergence seen just south of bar mouth increases with period.

In the case of waves from 300°, divergence is noticed around Fort Kochi. For 6 sec. waves mild convergence is noticed around Azhikkal. and also between Narakkal and Kuzhippilly. The tendency of convergence that is seen near Narakkal for higher periods again disappears for 9 sec.

Long shore currents:

The direction of long shore currents at any place can be obtained by evaluating the direction that the wave ray makes with the normal to the coastline before wave breaking. The estimation of this at selected locations for different periods and directions will form part of future investigation on the stability of beaches. However, some inferences on this are drawn here from the wave rays in the refraction diagrams. At those locations where the water carried by long shore currents accumulates, swift and narrow currents directed away from the shore are generated. These are called rip currents. Rip currents are attributed to the long shore head of water produced by differences in wave set up (Bowen, 1963; Bowen and Inman, 1969).

For 240°, predominant flow is northerly. However there appears to be a southerly component around Narakkal. This would result in the flows from opposite directions to meet near Malippuram and the formation of rip currents here. Another zone of southerly component is just north of Pallippuram for 9 sec waves.

For 270°, predominant northerly or southerly currents are not discernible. However there is an indication of strong northerly currents at Puthuvyppu, which may lead to rip currents at Narakkal.

As expected, for 300° generally southerly currents are seen. A probable zone of northerly current is the shoal just north of bar mouth, which can generate rip currents around Malippuram. This is in agreement with findings of Das *et.al.* (1966) who had deduced northerly currents in this region for 5 and 6 sec waves from these directions (290.5°).

Based on refraction studies by graphical method Shenoi and Prasanna kumar(1982) observed that for waves of 6 and 8 sec. from 240°, slight erosion all along present study area. For 10 sec., deposition in Kochi and erosion along the stretch from Vypin to Narakkal were also noticed. Though depositional regions agree in the present study, erosion is found to be limited to Malippuram and around Kuzippilly. Also, deposition north of Narakkal and near Mundamveli agrees with present findings. Present study, in general, agrees with deposition all along for 300°, except the mild erosion at Azhikkal and for higher period waves.

Das *et.al.* (1966) have noticed erosion at Narakkal. Present study does not indicate erosion at Narakkal during southwest monsoon. However erosion just north at Kuzhippilly is seen. It may be noted that they had not mentioned the different places separately and that they might be considering the neighbouring places also as Narakkal. It may be noted that Rao *et. al.* (1982) have given photographs of severe erosion during southwest monsoon at Edavanakkad and Kuzhippilly, north of Narakkal. Area of erosion at Chellnam as reported by Das *et.al.* (1966) could not be clearly seen in present study because the boundaries of grid area were found to be inadequate for waves from 240° to reach this location.

While studying shoreline changes along Kerala coast Ravindran *et. al.* (1971) noticed accretion in Vypin. Present study also indicates that during southwest monsoon period when high waves can be expected, i.e. from 240° and 270°, divergence and therefore deposition occur at the shoals. However, at northern end of the shoals conspicuous erosion occurs. Therefore it is natural to expect that over the years, the shoal get eroded from the northern side. It is more so because during fair weather season also (i.e. waves from 300°) erosion is possible here. Hence there must be some mechanism for maintaining the shoals. In a somewhat similar situation at Vishakhapatnam, Dhanalakshmi (1982) observed strong convergence near a shoal formed by the dumping of the material dredged for the construction of a harbour and that the shoal got completely eroded in about 12 years. In the case of Cochin harbour, the materials of the maintenance dredging of the shipping channel are dumped offshore. It is believed that at least a part of this finds its way to the present shoal (Murty *et. al.*1984), thus providing necessary supply for its maintenance. Changes in the site for the dumping of dredged material may lead to erosion of the shoal off Azhikkal and Puduvyppu.

It is interesting to note that rip currents occur around Malippuram for 240° and 300° and at Narakkal for 270°. Since higher waves are expected during southwest monsoon, stronger rip currents are possible then off Malippuram and Narakkal. Rip currents carry sediments off shore. It would be worthwhile to examine whether these have any implications on the formations of mudbanks (Chakara) in these regions. Mudbanks occur irregularly off Vypin and Narakkal during this season. Based on wave refraction and field studies, Varma and Kurup (1969) observed rip currents at a mudbank region near Alappuzha. They suggested that the sediment carried offshore by rip currents and those brought in by the action of high monsoon waves converge in off shore region. This accumulation of suspended sediment has been considered as the reason for wave damping and hence for the mud bank formation there.

In a similar way, the rip currents in the present study may have some bearing on the mud banks occurring off Puduvyppu and Narakkal. Variation in rips depending on the changes in wave characteristics and topography may lead variations in mud bank. Recently while discussing the detailed current and wave measurements in the mudbank region near Alappuzha, Tatrvati *et.al.* (1999) also indicated the importance of undertow in carrying the sediments offshore.

CONCLUSIONS

It is seen that the shore-line north of Cochin bar mouth is more disturbed by the wave refraction. During southwest monsoon period, erosion is seen around Malippuram. During this period erosion is possible at Pallippuram also while deposition is possible at Narakkal. During fair weather period generally mild erosion is seen at the shoals (Azhikkal).

Directions of long shore currents inferred from the wave rays in the refraction diagrams indicate zones of rip currents around Malippuram and Narakkal. These may have implications in the formation of mudbanks (Chakara) off Vypin and off Narakkal, some times during southwest monsoon.

It is surmised that any change in the present site for the dumping of material dredged for the maintenance of the shipping channel may lead to erosion of the shoal off Azhikkal and Puduvypu.

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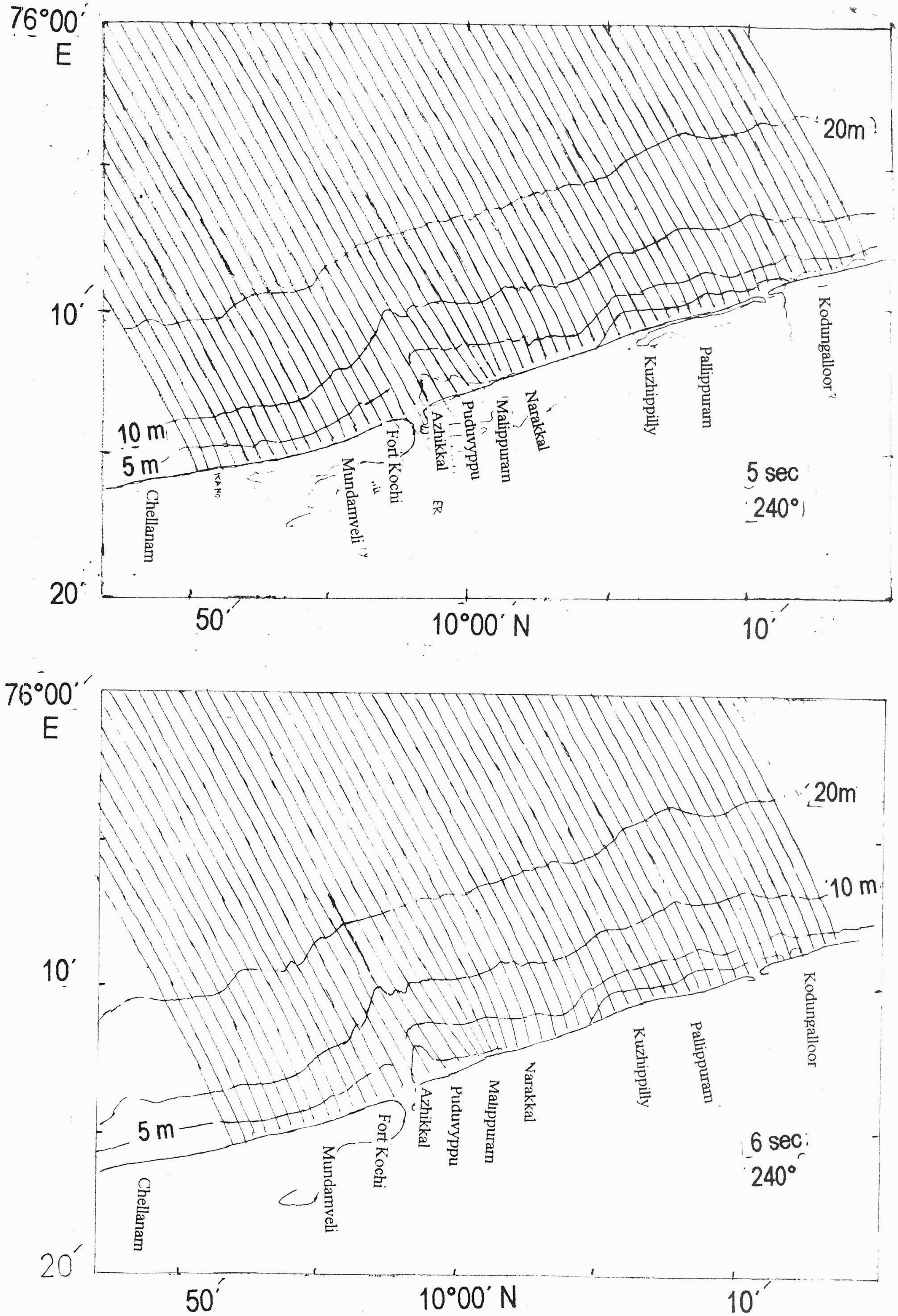
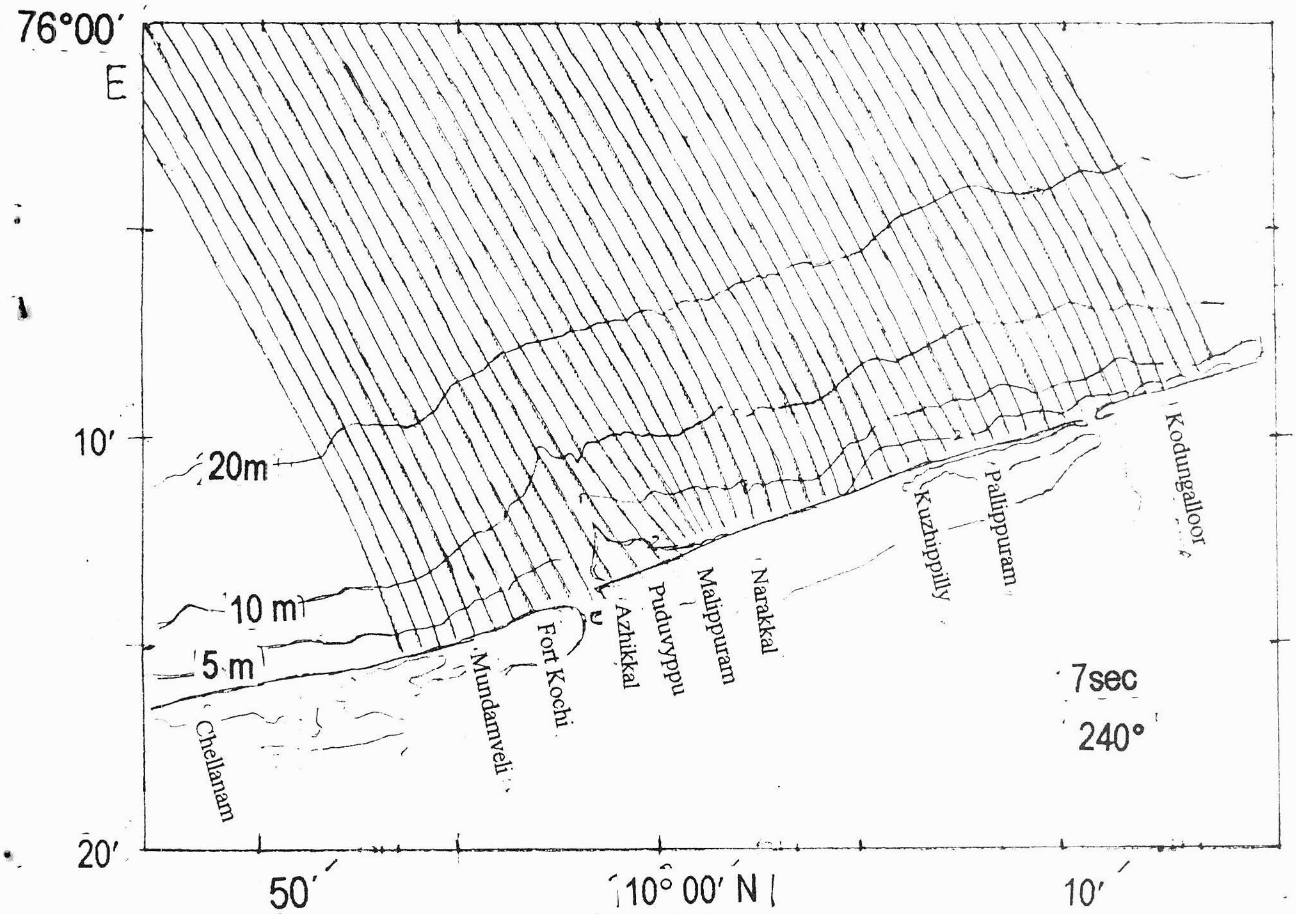


Fig.1.a. Refraction diagrams for waves of periods 5 and 6 seconds, approaching from 240 °T



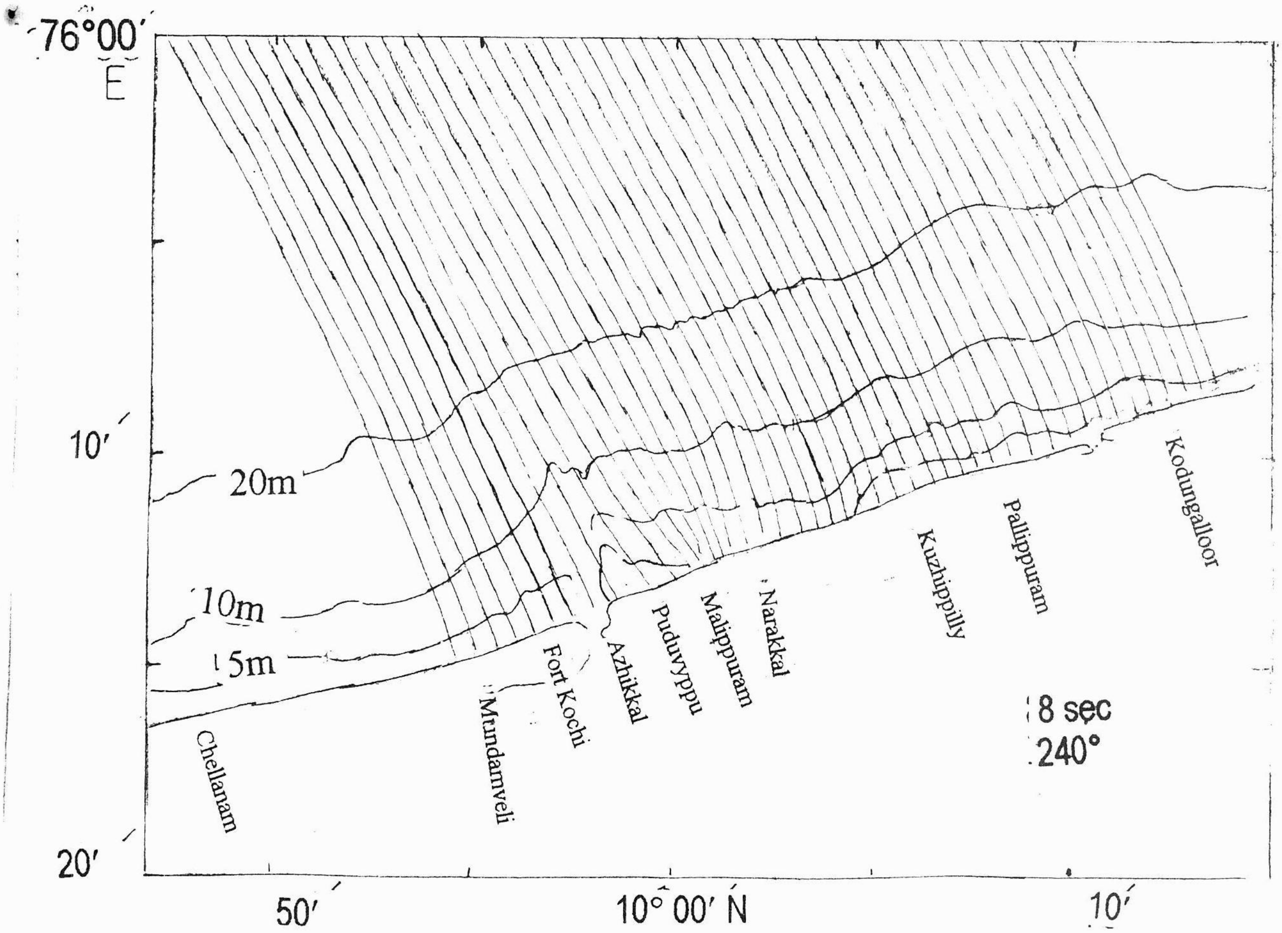


Fig.1.b Refraction diagrams for waves of periods 7 and 8 seconds, approaching from 240 °T

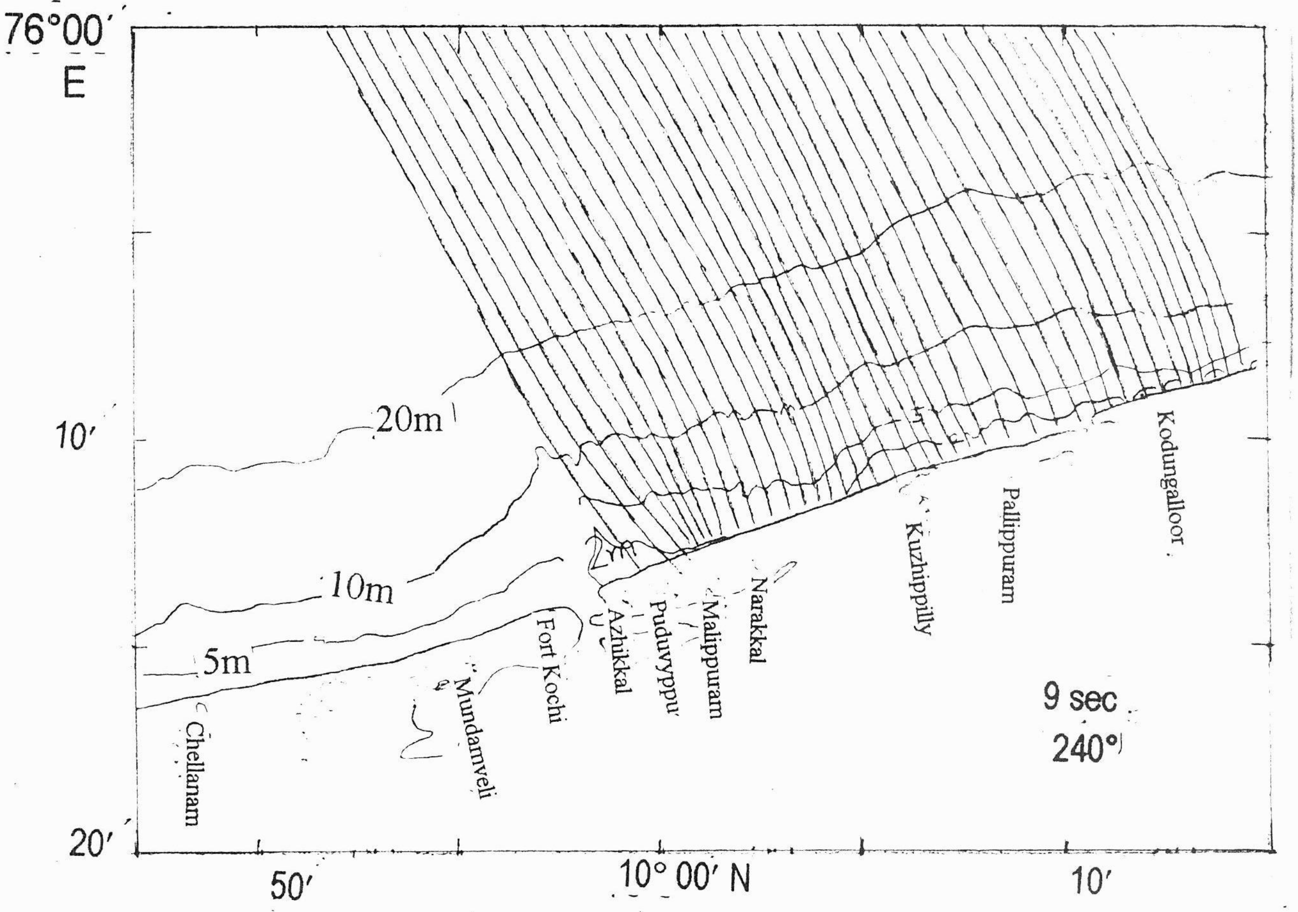


Fig.1.c. Refraction diagrams for waves of period 9 seconds, approaching from 240°T

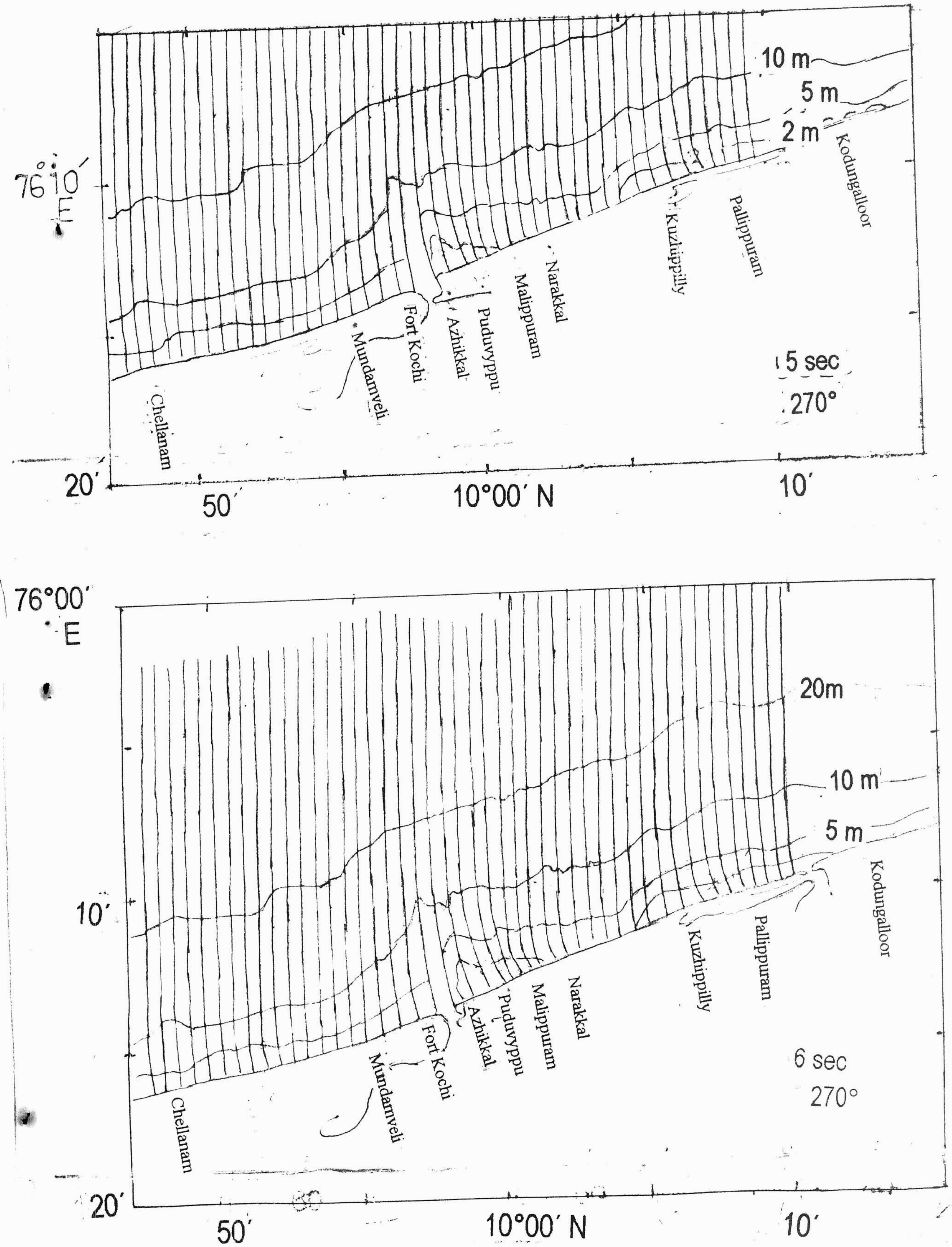
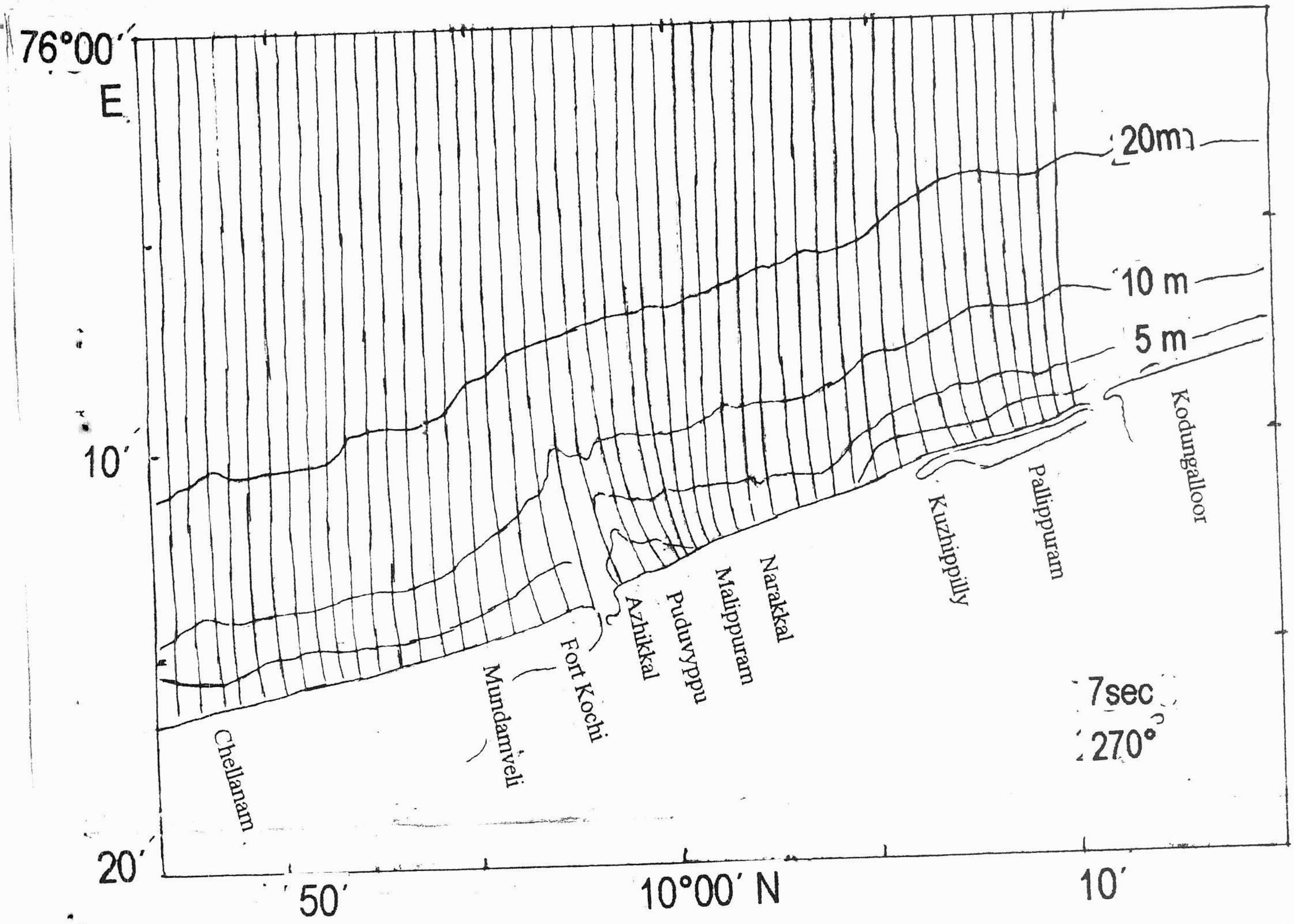


Fig.2.a. Refraction diagrams for waves of periods 5 and 6 seconds, approaching from 270 °T



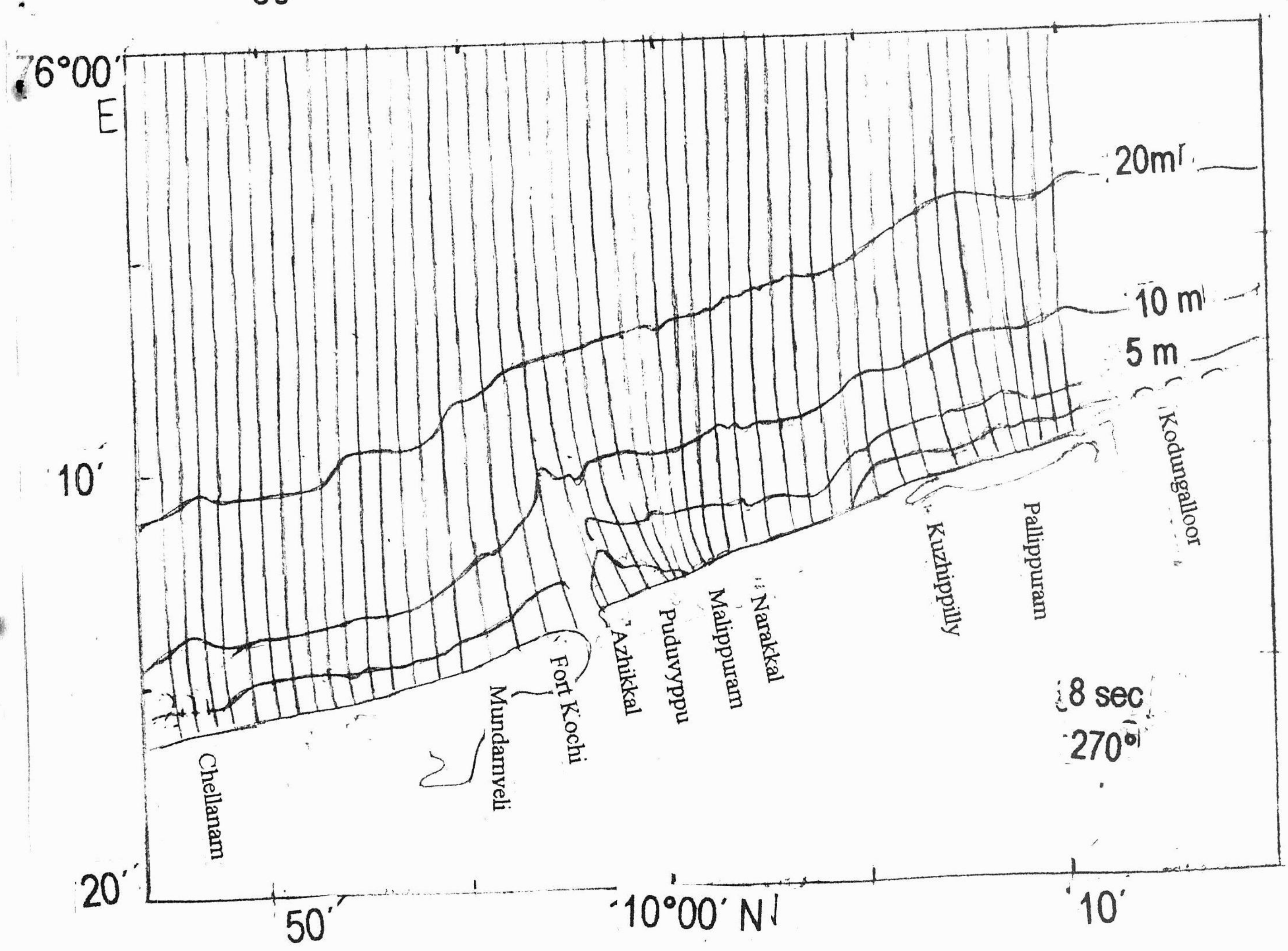


Fig.2.b Refraction diagrams for waves of periods 7 and 8 seconds, approaching from 270 °T

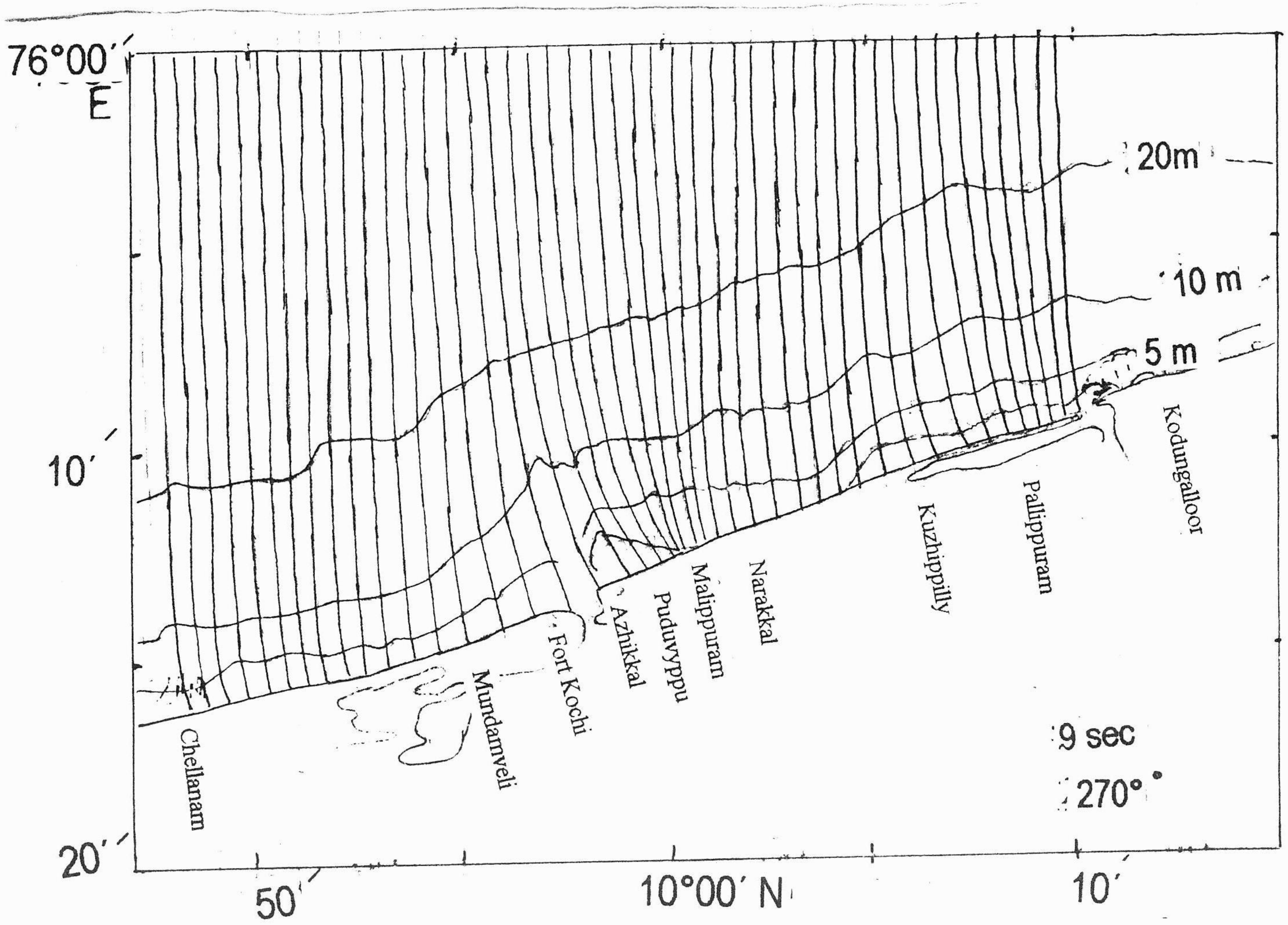
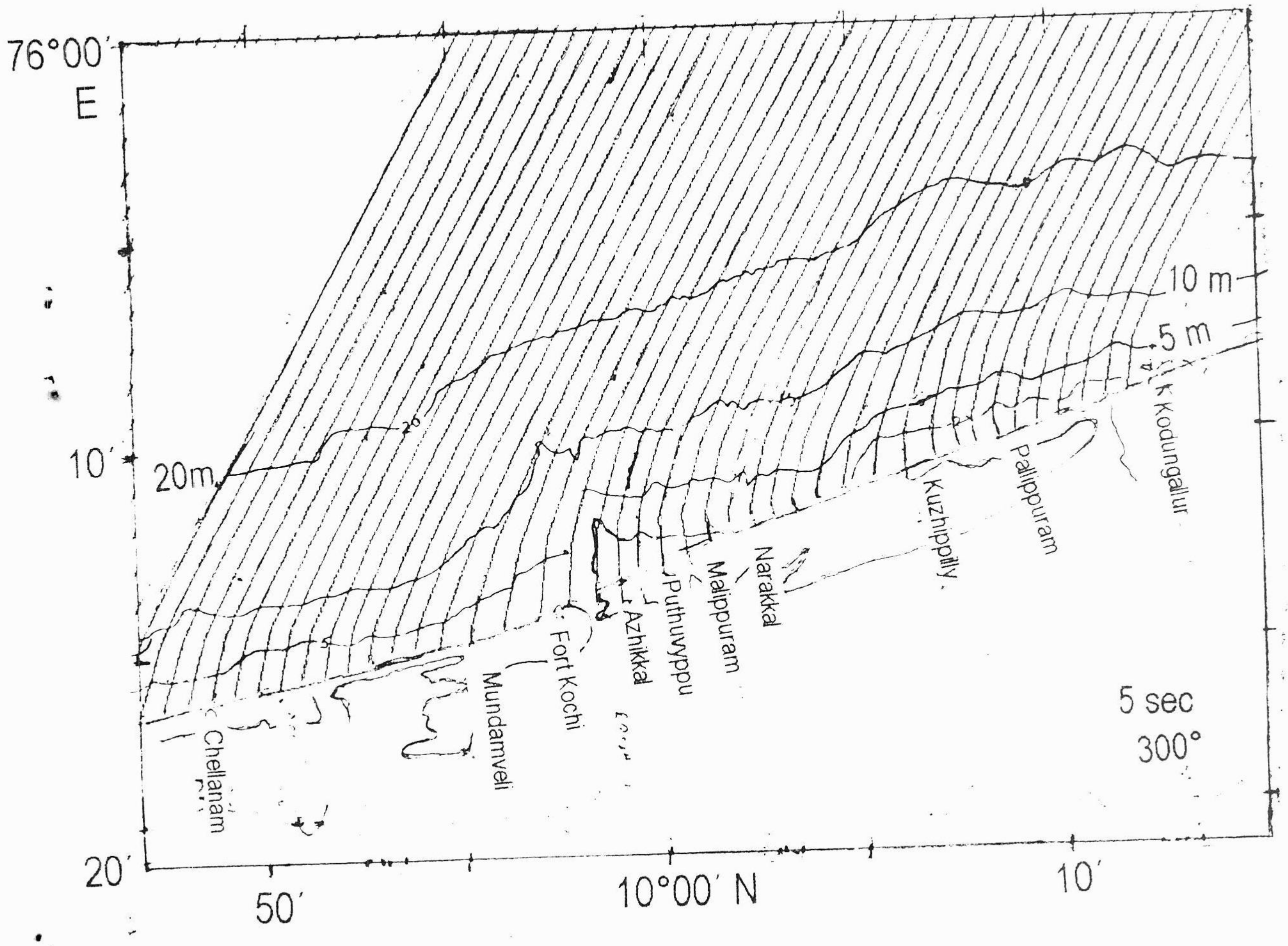


Fig.2.c. Refraction diagrams for waves of period 9 seconds, approaching from 270°T



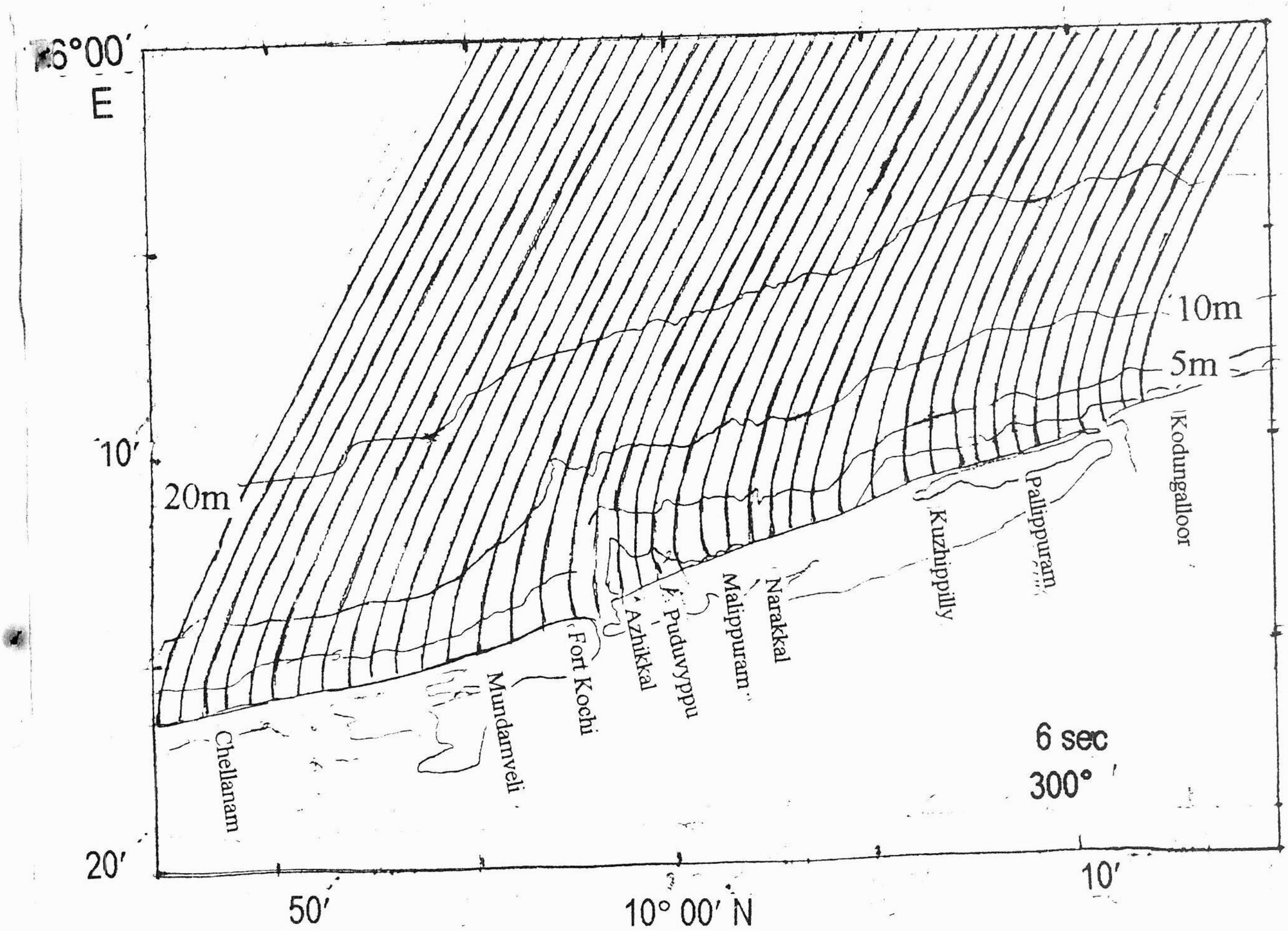
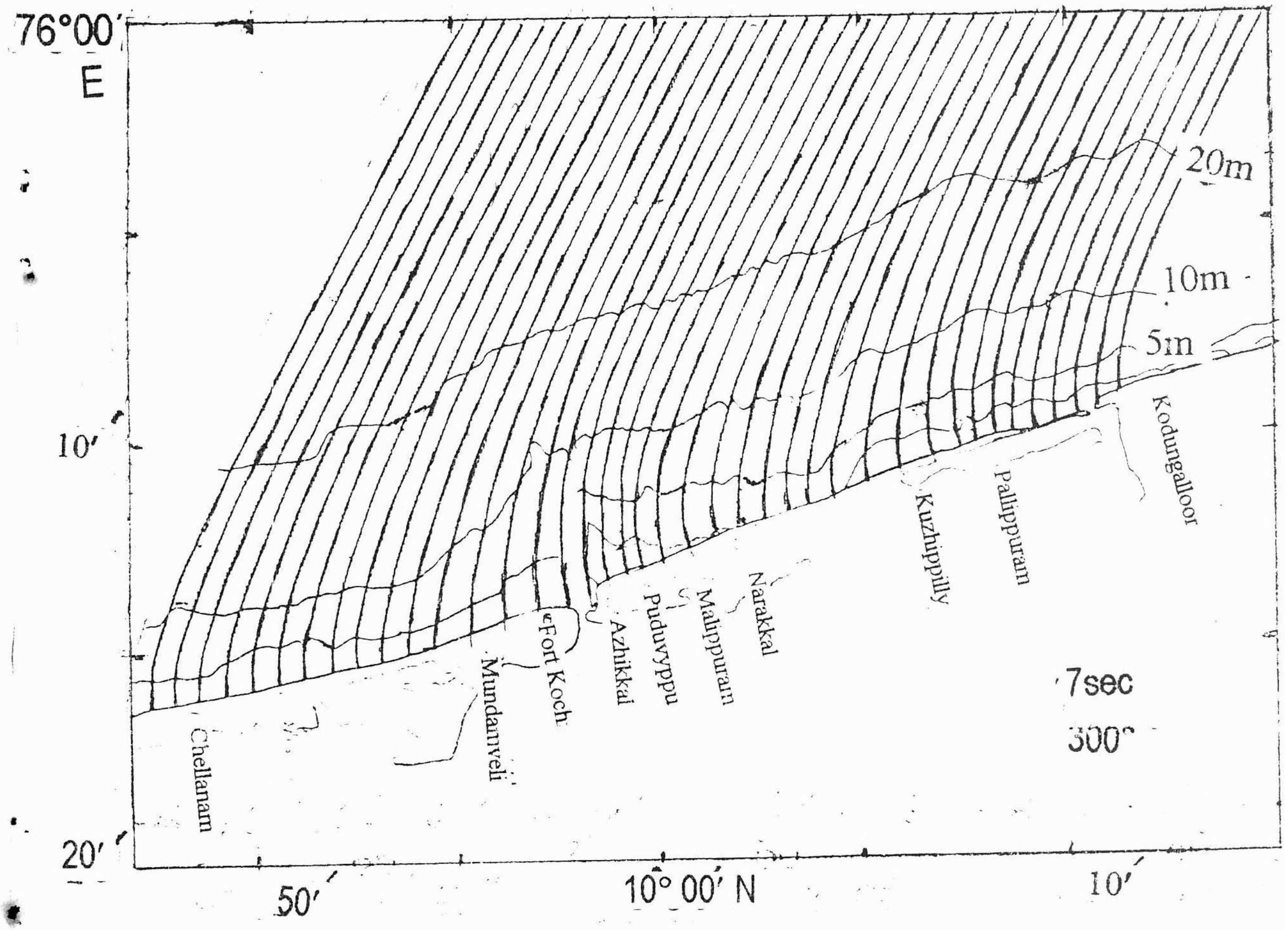


Fig.3.a. Refraction diagrams for waves of periods 5 and 6 seconds, approaching from300 °T



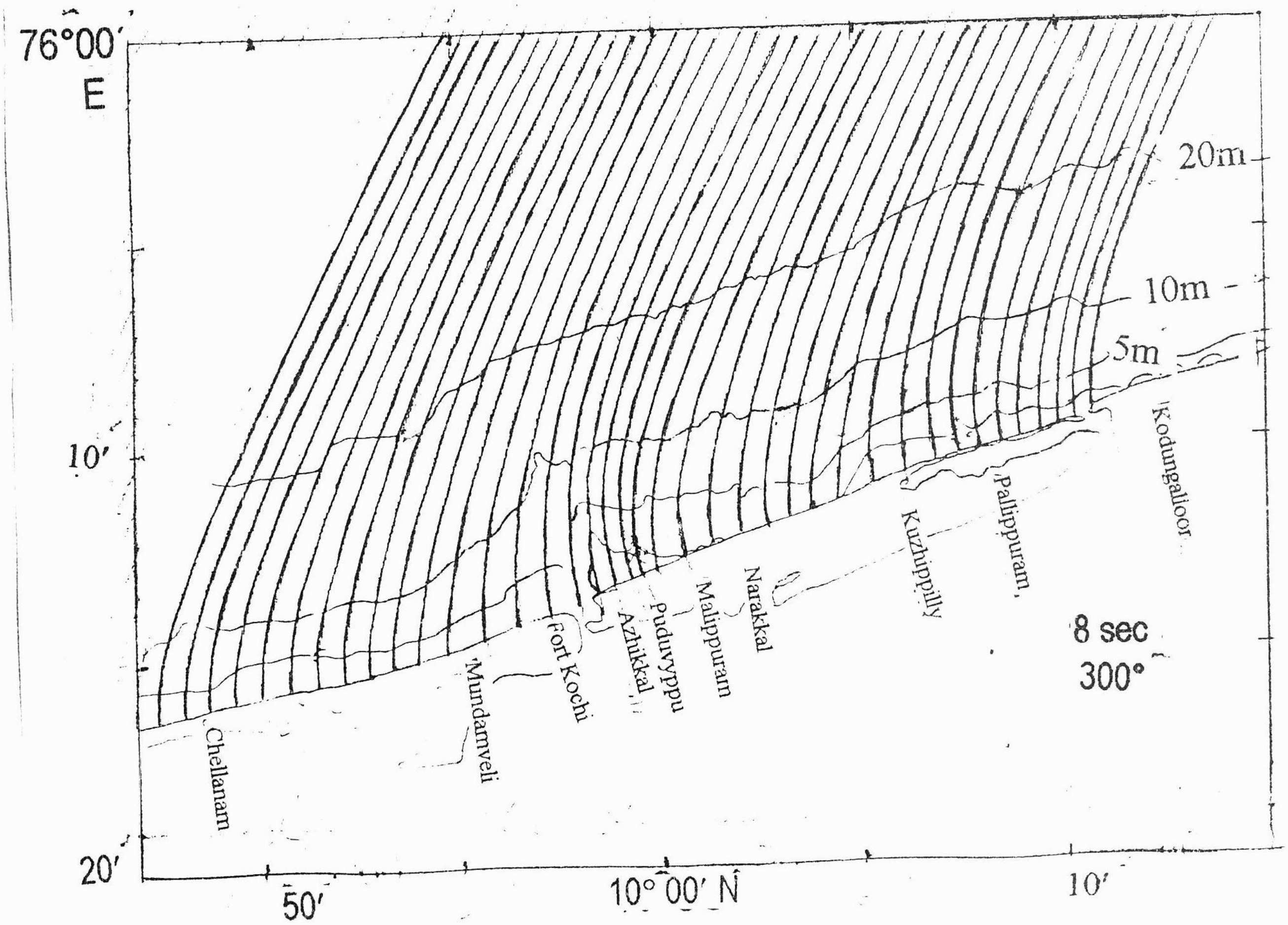


Fig.3.b. Refraction diagrams for waves of periods 7 and 8 seconds, approaching from 300°T

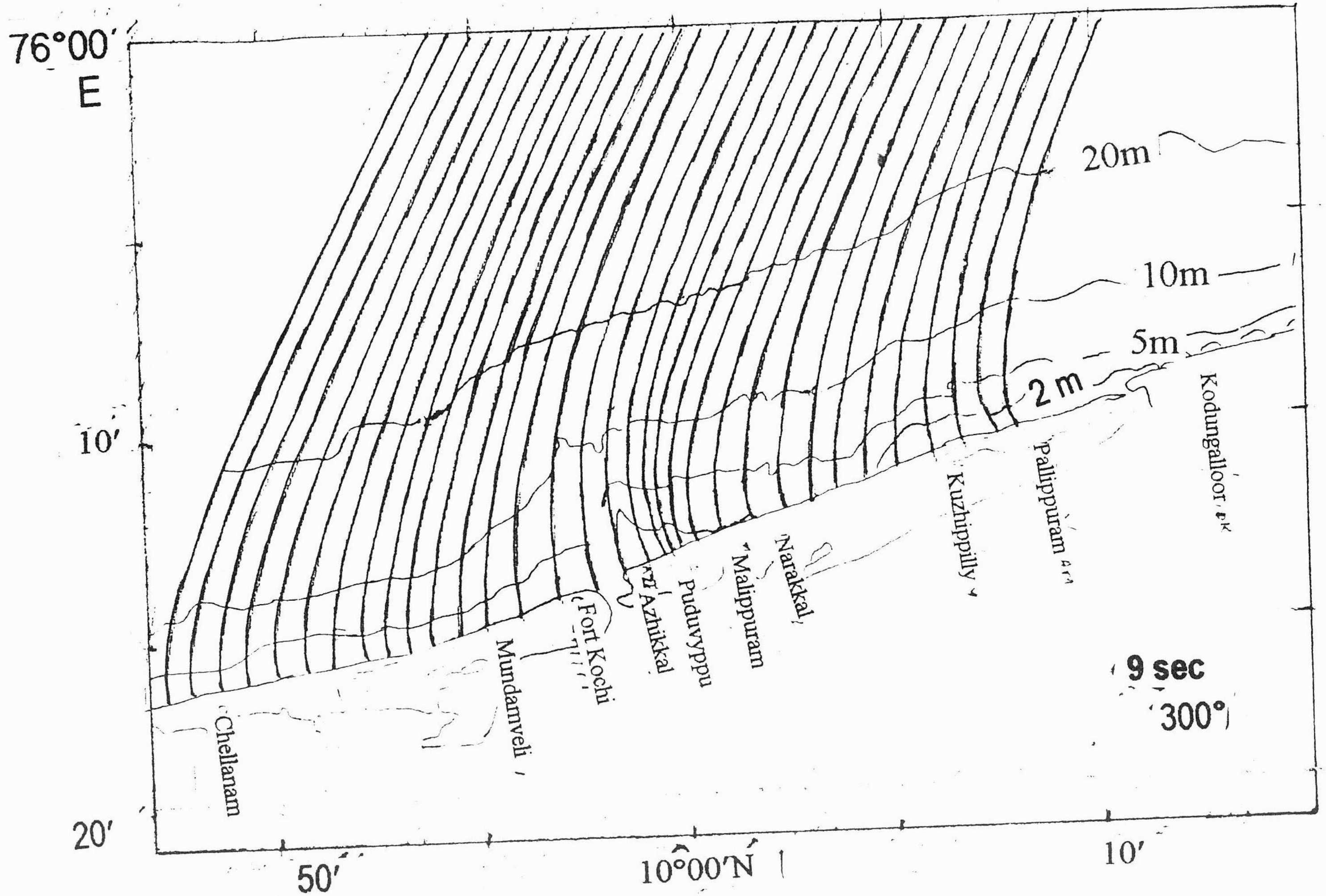


Fig.3.c. Refraction diagrams for waves of period 9seconds, approaching from300 °T

APENDIX I COMPUTER PROGRAMME

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c     Program for computation of wave refraction
c     Based on the programmes presented by Dobson(1967) and
c     the modified version by Kurian and Baba(1988).
c     mi - no. of x-grid units - not to exceed 100
c     mj - no. of y-grid units
c     limnpt - max. no. of ray computation
c     nprint - frequency of printed output for each ray
c     *** - all in format I5
c     grid - width of one off-shore grid
c     deltas - minimum  step length along ray in shallow water
c     grinc - step length along ray in deep water
c     *** - all in format f10.5
c     dep(i,j) - depth at grid points
c     nosets- no. of . ays in a set
c     titl - identifying title for each set
c     norays - no. of rays in each set
c     t - wave period
c     ho-  deep water wave height
c     x,y - starting coordinates
c     a - initial direction of ray
c     sxy - special unit matrix for use with a square grid
c     fit - s.d. of least square surface
c     resmax - limiting difference betwn. successive approximations
      common dep(100,100),d(12),e(6),b1,b2,co,cxy,dcdh,dcon,deltas,
     1drc,dtgr,dxy,grinc,ho,igo,jgo,limnpt,nprint,npt,phx,phy,rcco,
     1rhs,rk,sig,sk,top,v,wl,wlo,sxy(12,6),nn(7),hnew,titl(18)
 51   format(4i5,3f10.5)
 550  format(12f10.8)
 600  format(2f10.6,f12.10,2i4)
 400  format(i1)
  31  format(f5.2)
 56   format(i5)
 57   format(18a4)
 58   format(i3,f8.2,f6.2)
 59   format(2f7.3,f8.3)
 71   format(1h1,18a4,'set no.',i3,'period =',f7.2,'secs  ',
     1'ray no. = ',i3)
 61   format(1h1,18a4/1X,'set no.',i3,'period ='f7.2,'secs  ',
     1'ray no = ',i3,'time step =',f8.2,'secs'//1h,3x,'POINT',
     15x,1hx,8x,1hy,6x,'ANGLE',5x,'DEPTH',4X,'MAX DIF',4X,'FIT',4X
     1,'LENGTH',4X,'SPEED',4X,'HEIGHT',6X,'KR',7X,'KS'
     1//1H ,I7,3f9.2,29x,3f9.2)
 62   format(1h0,'all sets completed ; no. of sets =',i4)
 63   format (1h0,9x,'program parameters'//1h,'grid limits',
     1' absica = ',i3,'    ordinates = ',i3,/1h,'printed output' ,
     1'interval = ',i2,'point'/1h,'grid size unit = ',f8.2,'metres',
     11h,'    deep water incremental step =',f4.2,'grid units ')
 64   format(1h0,'PROGRAM STOPPED MI GREATER THAN 75 OR MJ
     1GREATER THAN 75 NOT ALLOWED, MI = ',I4,'MJ = ',I4)
 1000 format(15f5.1)
c     read basic data
      read(7,550)((sxy(i,j),i = 1,12),j = 1,6)
c     identifier to select rays
      indray=0
```

```
      read(7,51) mi,mj,limnpt,nprint,grid,deltas,grinc
      write (*,*) mi,mj,limnpt,nprint,grid,deltas,grinc
      if(mi.gt.75 .or. mj.gt.75 ) go to 10
      read(7,1000)((dep(i,j),i = 1,mi),j = 1,mj)
      rhs = mi
      rhs = rhs-1.99
      top = mj
      top = top-1.99
 18   write(1,63)mi,mj,nprint,grid,grinc
c     read wave data
      read (7,56)nosets
      do 110 noset = 1 , nosets
      read(7,57) titl
      read(7,58)norays,t,ho
      write(*,58)norays,t,ho
      sig = 6.28318531/t
      co = 1.5606255*t
      write(*,*) co
      dtgr = grinc/co
      unit =dtgr*grid
      wlo = co*t
      drc = wlo*.6
      write(*,*)dtgr,wlo,drc,co
      do 110 noray = 1 ,norays
      read(7,59)x,y,a
      write(*,152)noset,noray,x,y,a
 152  format( 'CALCULATION IN PROGRESS ,SET NO = ',I3,'  RAYN0 = '
     1,I3,' X = ',f5.1,' Y = ',f5.1,' A = ',f7.2 )
c     select wave ray
      ifr =1
      npt = 1
      cxy = co
      wl =wlo
      b1 = 1.
      b2 = 1.
      rk =1.
      sk =1.
      write(1,61)titl,noset,t,noray,unit,npt,x,y,a,wlo,co,ho
      hnew = ho
      call raycon(x,y,a)
 110  continue
      write(1,62)nosets
      goto 12
 10   write(1,64)mi,mj
 12   stop
      end

c     raycon
      subroutine raycon (x,y,a)
      common dep(100,100),d(12),e(6),b1,b2,co,cxy,dcdh,dcon,deltas,
     1drc,dtgr,dxy,grinc,ho,igo,jgo,limnpt,nprint,npt,phx,phy,rcco,
     1rhs,rk,sig,sk,top,v,wl,wlo,sxy(12,6),nn(7),hnew,titl(18)
      ang=a
      a= a*0.0174532925
```

```
      cosa = cos(a)
      sina = sin(a)
      h = ho
      igo = 1
c     take the wave to shallow water
   10 px = x
      py = y
      x = cosa*grinc+x
      y = sina*grinc+y
      if(x.ge.rhs.or.x.lt.1.01) goto 25
      if(y.ge.top.or.y.lt.1.01) goto 25
      call depth(x,y,xp,yp)
      nwrite= 1
      if(dxy.le.0) goto 24
      if(dxy.lt.drc) goto 11
      npt = npt+1
      if(npt.gt.limnpt) goto 26
      if(npt/nprint*nprint-npt.ne.0) goto 10
      go to 21
c     shallow water refraction begins
   11  x = px
       y = py
       call curve(x,y,a,fk,xp,yp)
   12  npt=npt+1
       if (npt .gt. limnpt) go to 26
       nwrite=1
       call refrac(x,y,a,fk)
       do 205 i=1,7
       if (nn(i)  .eq. 18) go to 18
       if (nn(i)  .eq. 22) go to 22
       if (nn(i)  .eq. 23) go to 23
       if (nn(i)  .eq. 24) go to 24
       if (nn(i)  .eq. 25) go to 25
       if (nn(i)  .eq. 27) go to 27
       if (nn(i)  .eq. 28) go to 28
  205 continue
   22 nwrite=2
        go to 18
   23 nwrite=3
        go to 18
   24 nwrite=4
        go to 13
   25 nwrite=5
        go to 13
   26 nwrite=6
        go to 13
   27 nwrite=7
        go to 13
   28 nwrite=9
        go to 21
   18  call height (xp,yp,a,h)
        if (nwrite .gt. 1) go to 13
        if(npt/nprint*nprint-npt.ne.0) goto 12
   13  ang= a*57.29577931
```

```
 21  call writer (x,y,ang,h,nwrite)
 14  go to(10,12,19),igo
 19  return
     end

c    refrac
     subroutine refrac(x,y,a,fk)
     common dep(100,100),d(12),e(6),b1,b2,co,cxy,dcdh,dcon,deltas,
    1drc,dtgr,dxy,grinc,ho,igo,jgo,limnpt,nprint,npt,phx,phy,rcco,
    1rhs,rk,sig,sk,top,v,wl,wlo,sxy(12,6),nn(7),hnew,titl(18)
     do 200 i = 1,7
200  nn(i) = 0
     ncur = 1
c    bring the wave for refraction
     goto (11,12,10) igo
 11  fkm = fk
     igo = 2
 12  ds= cxy*dtgr
     if(ds.lt.deltas) nn(6)= 27
     if(nn(6).eq.27) return
     resmax = .00005/ds
 13  do 110 i = 1,20
     dela = fkm*ds
     if(abs(dela).ge.1) nn(7) = 28
     if(nn(7).eq.28) return
     aa = a+dela
     am = dela*.5+a
     xx  = cos(am)*ds+x
     yy = sin(am)*ds+y
     call curve (xx,yy,aa,fkk,xp,yp)
     if(dxy.le.0.1) nn(4)= 24
     if(nn(4).eq.24) return
     goto (111,16) ncur
 111 fkm = (fk+fkk)*.5
     if(i.eq.1) goto 110
     if(resmax .gt.abs(fkp-fkm)) goto 16
     if(i.eq.18) fk18= fkm
110  fkp = fkm
     if(resmax.gt.abs(fk18-fkm)) goto 15
     nn(3) = 23
     return
 15  fkm = (fkm+fk18)*.5
     ncur = 2
     goto 13
 16  x = xx
     y = yy
     a = aa
     fk = fkk
     if(ncur.eq.2) nn(2)=22
     if (nn(2) .eq. 22)  return
     if(x.ge.rhs .or. x.le.(1.0)) nn(5) = 25
     if(nn(5).eq. 25) return
     if(y.ge.top .or. y.le.(1.0)) nn(5)=25
     if(nn(5).eq.25) return
```

```
      nn(1) = 18
   10 return
      end

c     curve
      subroutine curve(x,y,a,fk,xp,yp)
      common dep(100,100),d(12),e(6),b1,b2,co,cxy,dcdh,dcon,deltas,
     1drc,dtgr,dxy,grinc,ho,igo,jgo,limnpt,nprint,npt,phx,phy,rcco,
     1rhs,rk,sig,sk,top,v,wl,wlo,sxy(12,6),nn(7),hnew,titl(18)
      go to(10,11)igo
   11 call depth(x,y,xp,yp)
      if(dxy*200.gt.wl) goto 10
      if(dxy .lt. 0)return
      jgo = 2
      arg = 9.806278*dxy
      cxy = sqrt(arg)
      dcdh = 4.9/cxy
      goto 14
   10 ci=cxy
      jgo =1
      do 120 i = 1,2
      arg = (dxy*sig)/ci
      cxy = co*tanh(arg)
      resid = cxy-ci
      if(abs(resid).lt..0001) goto 13
  120 ci = (cxy+ci)*.5
   13 rcco = cxy/co
      scmc = (1-rcco**2)*sig
      v=scmc*dxy+rcco*cxy
      dcdh=cxy*scmc/v
   14 phx = e(4)*2*xp+e(5)*yp+e(2)
      phy = e(6)*2*yp+e(5)*xp+e(3)
      sina=sin(a)
      cosa=cos(a)
      fk = (sin(a)*phx-cos(a)*phy)*dcdh/cxy
      return
      end

c     depth
      subroutine depth(x,y,xp,yp)
      common dep(100,100),d(12),e(6),b1,b2,co,cxy,dcdh,dcon,deltas,
     1drc,dtgr,dxy,grinc,ho,igo,jgo,limnpt,nprint,npt,phx,phy,rcco,
     1rhs,rk,sig,sk,top,v,wl,wlo,sxy(12,6),nn(7),hnew,titl(18)
      i = x+1.
      j = y+1.
      xp =amod(x,1.)
      yp= amod(y,1.)
      if(npt.eq.1) goto 11
      if(ip.ne.i) goto 11
      if(jp.eq.j) goto 14
   11 ip = i
      jp = j
      d(1) = dep(i,j)
      d(2) = dep(i+1,j)
```

```
12  igo=3
11  return
    end

    subroutine height(x,y,a,h)
c   programme for height calculation
    common dep(100,100),d(12),e(6),b1,b2,co,cxy,dcdh,dcon,deltas,
   1drc,dtgr,dxy,grinc,ho,igo,jgo,limnpt,nprint,npt,phx,phy,rcco,
   1rhs,rk,sig,sk,top,v,wl,wlo,sxy(12,6),nn(7),hnew,titl(18)
    wl = wlo*rcco
    gn = 12.5663706144*dxy/wl
    sh =(exp(gn)-exp(-gn))/2.
    cg = (1.+gn/sh)*cxy
    if(cg.lt.0) return
    sk = sqrt(co/cg)
    rk =abs(1./b2)
    rk = sqrt(rk)
    h = ho*rk*sk
    hnew=h
    goto (11,12)jgo
11  u = -2.*sig*rcco*cxy/(v*v)
    go to 10
12  u = -.5/dxy
10  cosa = cos(a)
    sina = sin(a)
    p = -(cosa*phx+sina*phy)*dcdh*dtgr*2.
    q = ((e(4)*2.+u*phx*phx)*sina*sina-(e(5)+u*phx*phy)*2.*sina*
   1cosa+(e(6)*2.+u*phy*phy)*cosa*cosa)*dcdh*cxy*dtgr*dtgr*2.
    b3 = ((P-2.)*b1+(4.-q)*b2)/(p+2.)
    b1 = b2
    b2 = b3
    return
    end

    subroutine error(fit,difmax)
c   progrmme for finding error in depth computation
    common dep(100,100),d(12),e(6),b1,b2,co,cxy,dcdh,dcon,deltas,
   1drc,dtgr,dxy,grinc,ho,igo,jgo,limnpt,nprint,npt,phx,phy,rcco,
   1rhs,rk,sig,sk,top,v,wl,wlo,sxy(12,6),nn(7),hnew,titl(18)
    dimension dp(4)
    if(npt.lt.3) go to 11
    if(ep.eq.e(5)) go to 12
11  dp(1) = e(1)
    dp(2) = e(1)+e(2)+e(4)
    dp(3)= e(1)+e(2)+e(3)+e(4)+e(5)+e(6)
    dp(4)=e(1)+e(3)+e(6)
    difmay = 0
    sum = 0
    do 110 i = 1,4
    dif = abs(d(i)-dp(i))
    if(difmay.lt.dif) difmay=dif
110 sum = sum+dif*dif
    sum = sum*.25
    fit = sqrt(sum)
    ep =e(5)
12  difmax = difmay/dxy*100.
    return
    end
```

APENDIX II SAMPLE DATA

```
 .30861241 .23664207 .21770331 .23664207-.08492823-.05144354-.05144354-.08492833 .00598086 .13038277 .13038277 .00598086
 .05322984 .19677030 .14413872 .10586122 .09031100-.06758374-.03439283 .03439282-.18241626-.34031099-.12440190 .12440190
 .05322964 .10586122 .14413872 .19677030 .03349282-.03349283-.06758374 .09031099 .12440190-.12440191-.34031999-.18241625
-.12499998-.12499998-.12499998-.12499998 .125      .125      .0        .0        .12499999 .12499999 .0        .0
 .05263157-.05263157 .05263158-.05263157-.15789473 .15789474 .15789474-.15789473-.15789473 .15789473 .15789473-.15789473
-.12499998-.12499998-.12499998-.12499998 .0        .0        .125      .125      .0        .0        .12499999 .12499999
  38   36  300     51853.0          .005      .5
 -4.5 -4.0 -4.0 -3.5 -3.5 -3.0 -3.0 -3.0 -3.0 -2.5 -2.5 -2.0 -1.8 -1.5 -1.5
 -1.6 -1.3 -1.0  -.8   .0  -.5  -.2   .0  3.8  4.8  5.8  6.0  6.1  7.2  8.0
  9.2  9.8 10.8 11.8 11.8 11.8 11.8 12.0 -4.5 -4.0 -4.0 -3.5 -3.5 -3.0 -3.0
 -3.0 -3.0 -2.2 -1.8 -1.3 -1.3 -2.0 -1.0 -1.0  -.8  -.8  -.5  2.0  3.0  4.5
  6.0  8.0  8.2  9.0 10.0 10.2 11.5 11.8 12.0 12.2 13.2 14.2 15.0 15.0 15.2
 15.5 -4.0 -3.5 -3.5 -3.0 -3.0 -2.5 -2.5 -2.0 -1.6 -1.2 -1.0  -.8  -.8  -.8
  -.5  -.6  -.5  -.2  1.2  3.0  4.5  7.2  9.1 11.2 12.0 12.3 13.0 14.0 14.2
 14.7 15.5 15.5 15.5 16.4 17.8 17.5 17.2 17.2 -4.0 -3.5 -3.5 -3.0 -3.0 -2.5
 -2.5 -1.5 -1.0 -1.0  -.8  -.5  -.5  -.2   .0  1.8  1.9  3.2  3.5  4.0  6.6
 10.0 12.2 14.0 15.0 15.5 16.0 16.2 16.2 17.8 18.0 18.0 18.2 19.0 19.0 19.0
 19.0 19.0 -3.5 -3.0 -3.0 -2.0 -2.0 -1.5 -1.5 -1.0  -.8  -.5  -.2   .0  1.0
  5.0  6.0  6.0  6.0  6.5  6.8  8.0  7.9 12.5 15.0 17.0 17.0 17.8 18.8 19.2
 20.0 20.0 20.3 20.0 20.0 21.0 21.0 21.5 21.0 20.8 -3.0 -2.5 -2.5 -1.5 -1.5
 -1.0   .8   .0   .8  2.0  2.4  3.0  5.0  8.0  8.5  8.5  8.8 10.5 10.0 10.5
 11.0 15.0 17.5 19.8 20.0 21.9 22.0 22.0 21.7 21.7 21.8 21.8 22.0 22.8 23.0
 23.0 23.2 23.0 -2.5 -2.5 -2.0 -1.0 -1.0   .0  2.5  4.0  4.3  5.2  6.0  7.2
  8.4 10.2 11.0 11.0 12.0 14.0 14.0 14.0 15.0 17.5 19.3 22.1 23.0 23.0 24.0
 23.5 23.2 23.2 23.2 23.2 23.8 25.0 25.0 25.0 24.8 24.5 -1.0   .0  3.8  5.5
  6.0  5.7  6.0  7.0  7.2  8.2  9.2 10.5 11.5 12.5 14.0 14.9 16.5 17.0 17.1
 17.7 19.0 20.1 22.1 24.2 25.5 25.8 25.5 25.2 25.0 25.0 25.0 25.2 25.8 26.5
 26.5 26.7 26.5 27.0  6.0  8.0  8.3  9.3 10.0 10.0 10.0 10.0 11.5 11.3 12.0
 12.8 15.0 16.0 16.9 18.0 19.2 20.1 20.1 20.7 21.2 22.4 24.3 26.2 27.8 28.0
 28.0 27.7 27.5 27.5 27.5 27.6 27.8 27.5 27.2 27.1 28.0 29.0 10.0 11.2 12.5
 14.0 14.5 14.5 14.2 14.5 15.0 14.8 15.0 16.5 18.5 20.0 20.0 21.0 21.8 21.9
 21.0 21.9 23.2 24.5 26.6 28.2 29.8 30.0 29.5 29.0 29.0 29.0 29.3 29.5 29.8
 28.5 29.0 29.0 30.0 30.8 13.5 14.2 15.5 16.8 17.5 17.5 17.3 17.3 17.6 17.9
 18.0 19.2 22.0 22.8 23.0 23.4 23.5 23.7 22.5 23.9 25.3 27.0 28.3 30.5 32.0
 32.0 31.5 30.7 30.5 30.8 31.0 31.2 31.2 30.8 30.8 31.0 31.5 33.0 16.8 17.8
 19.0 19.5 19.7 19.2 19.7 19.7 20.8 20.0 21.0 23.0 24.5 25.0 25.2 25.2 25.1
 25.2 25.0 26.0 27.2 28.8 30.2 32.2 33.8 34.2 34.0 33.5 33.5 33.5 33.5 33.8
 33.8 33.0 34.0 35.0 35.8 36.3 18.8 20.2 21.8 21.8 21.8 22.0 22.8 23.2 22.5
 23.5 24.5 25.2 26.8 28.0 28.0 27.2 27.0 27.0 27.6 28.0 29.2 30.8 32.2 34.0
 35.0 35.3 36.0 36.0 36.0 36.0 36.0 36.1 37.0 37.5 38.0 38.2 39.5 40.0 21.0
 22.2 23.0 23.2 23.5 24.2 24.8 25.5 26.0 26.5 27.0 27.2 28.7 29.2 29.2 29.0
 28.8 28.6 29.2 28.8 31.0 32.3 34.0 35.0 35.8 36.3 36.5 36.8 37.0 37.5 39.0
 40.0 40.2 41.8 42.2 43.0 43.5 44.0 24.2 24.2 24.7 25.0 25.2 26.5 26.0 27.0
 28.0 28.2 28.5 28.8 30.0 31.0 31.2 31.1 31.0 30.9 31.5 32.0 32.2 34.0 35.0
 36.0 36.8 37.2 37.5 37.8 38.2 40.0 41.5 42.2 43.2 44.0 44.5 45.8 46.5 47.0
 25.2 25.5 26.2 26.3 26.5 27.0 27.5 28.3 29.0 29.0 29.5 30.5 32.0 33.0 33.2
 33.3 34.0 34.0 34.0 34.0 34.0 35.1 36.0 37.2 37.8 38.0 38.5 39.5 41.0 42.5
 44.0 44.5 45.0 45.5 46.5 47.0 47.5 46.5 26.2 26.5 27.2 27.0 27.8 28.0 29.0
 29.3 29.8 29.9 31.0 32.5 33.5 34.6 35.2 35.7 36.1 36.0 35.7 35.6 36.0 36.8
 37.8 39.0 39.8 40.0 41.0 42.3 44.0 44.8 45.5 46.0 46.2 47.0 47.8 48.0 48.2
 48.5 27.2 27.3 27.5 28.0 28.2 29.2 30.5 31.2 31.8 31.7 33.0 34.5 35.5 37.0
 38.0 39.0 39.5 39.0 37.5 38.0 38.8 39.5 40.5 41.2 41.8 43.0 44.0 45.0 45.8
 46.2 46.5 47.0 47.8 48.3 48.5 48.8 49.0 49.3 28.2 28.2 28.8 29.3 29.9 31.5
 33.0 33.3 34.0 34.0 35.5 36.0 37.9 39.0 40.5 41.6 41.9 41.0 40.0 40.5 41.3
 42.0 43.0 44.0 44.2 45.2 46.0 46.5 46.8 47.2 47.5 48.0 48.5 49.0 49.0 49.2
 49.5 49.7 29.5 29.5 29.8 30.0 32.0 35.0 36.2 36.8 37.0 37.5 38.0 38.5 39.7
 41.2 42.5 44.6 44.7 44.0 43.8 44.0 44.2 45.0 45.2 46.0 46.2 46.8 47.2 47.5
 47.8 48.0 48.8 49.0 49.2 49.3 49.6 49.8 50.9 50.5 30.8 31.0 31.5 32.5 35.8
 37.5 38.2 39.0 39.5 40.0 40.5 41.0 42.2 42.8 44.0 45.8 46.2 46.4 46.3 46.8
```

```
47.0 47.3 47.3 47.8 48.0 48.0 48.5 49.0 49.2 49.5 49.5 49.8 49.8 49.9 50.5
52.0 53.0 55.0 33.0 34.0 35.0 36.2 38.8 40.2 41.2 42.0 42.5 42.8 43.0 43.3
43.4 43.7 45.0 46.7 47.2 47.6 48.0 48.3 48.5 48.6 48.4 48.7 48.7 49.5 50.0
51.0 53.0 53.0 53.5 54.0 54.0 56.0 57.0 58.0 60.0 62.0 38.0 38.0 38.2 40.0
41.8 42.8 44.0 45.0 45.5 45.6 45.6 45.5 45.5 45.7 46.0 47.5 48.0 48.4 48.9
49.1 49.3 49.7 49.1 49.5 49.8 53.0 55.0 55.0 56.0 57.0 57.0 58.0 60.0 62.0
63.0 64.0 65.0 66.0 42.0 42.0 42.0 43.0 44.5 46.0 46.8 47.2 47.7 48.0 48.4
49.0 49.8 49.0 48.2 48.3 48.7 49.2 49.7 50.0 51.3 50.0 49.8 50.0 53.0 57.0
58.0 60.0 60.0 60.0 60.5 61.0 64.0 66.0 67.0 68.0 70.0 71.0 44.0 44.2 46.0
46.5 47.0 48.0 48.2 49.0 49.2 49.4 50.0 51.2 51.5 51.0 49.8 49.2 49.3 50.0
51.2 52.4 53.8 53.3 53.0 55.0 58.0 60.5 61.0 62.0 62.0 63.0 63.0 65.0 67.0
70.0 73.0 74.0 76.0 78.0 46.0 47.5 48.0 48.2 49.0 50.0 51.0 51.5 51.5 51.3
52.2 52.8 53.1 52.6 51.4 49.9 50.0 52.4 53.8 54.8 56.3 56.6 57.5 60.5 61.0
62.0 62.0 63.0 64.0 64.0 66.0 69.0 72.0 73.0 74.0 76.0 79.0 80.0 49.5 49.7
50.0 51.0 53.0 55.0 55.0 54.7 54.0 53.8 54.4 54.4 54.7 54.2 53.4 52.5 52.7
54.8 56.0 57.2 58.8 60.0 61.3 63.0 64.0 65.0 65.0 66.0 66.0 67.0 68.0 71.0
74.0 80.0 82.0 83.0 85.0 86.0 53.0 53.0 56.0 57.0 58.0 58.0 58.0 57.3 56.5
56.3 56.6 56.0 56.3 55.8 55.4 55.0 55.4 57.2 58.8 59.7 61.3 62.5 63.8 66.0
67.0 67.0 67.0 67.0 67.0 68.0 70.0 75.0 76.0 82.0 84.0 85.0 88.0 90.0 58.0
59.0 60.0 62.0 62.0 62.0 62.0 60.0 59.0 58.8 58.8 57.6 57.9 57.4 57.4 57.5
58.1 59.6 61.0 62.0 63.8 65.0 66.3 68.0 68.5 68.0 68.0 68.0 68.5 70.0 75.0
80.0 81.0 85.0 86.0 88.0 91.0 93.0 62.0 64.0 66.0 66.0 67.0 66.0 65.0 64.0
62.5 67.7 60.1 59.2 59.5 59.0 59.4 60.0 61.0 62.0 63.0 64.8 66.3 67.5 68.9
72.0 73.0 72.0 72.0 72.0 72.0 75.0 78.0 83.0 87.0 87.0 89.0 91.0 95.0 97.0
68.0 70.0 73.0 73.0 71.0 70.0 69.0 67.5 65.5 65.0 63.4 62.5 62.5 61.5 62.0
63.3 64.3 65.0 67.0 67.5 68.8 70.0 73.0 80.0 84.0 86.0 85.0 83.0 81.0 81.0
82.0 87.0 89.0 90.0 92.0 95.0 98.0100.0 73.0 76.0 77.0 77.0 76.0 75.0 74.0
73.0 70.0 68.3 66.7 65.5 65.0 65.0 65.2 66.7 67.6 68.0 69.0 70.0 71.5 73.3
78.0 84.0 90.0100.0 98.0 90.0 88.0 88.0 88.0 91.0 92.0 93.0 95.0 98.0 99.0
103.0 81.0 82.0 82.0 82.0 81.0 80.0 80.0 80.0 77.0 73.0 70.0 68.5 67.5 68.5
69.5 70.0 75.0 78.0 77.0 74.5 74.3 76.6 82.0 90.0110.0210.0210.0110.0 95.0
94.0 95.0 95.0 96.0 98.0 99.0100.0105.0110.0 90.0 89.0 88.0 88.0 88.0 88.0
88.0 86.0 84.0 80.0 75.0 74.0 75.0 80.0 85.0 88.0 88.0 87.0 83.0 79.0 77.1
80.0 85.0 92.0170.0220.0220.0150.0105.0100.0 99.0 99.0 99.0100.0103.0108.0
110.0125.0100.0 95.0 94.0 93.0 93.0 94.0 95.0 92.5 89.0 86.0 82.0 80.0 85.0
92.0 97.0100.0100.0 95.0 90.0 83.0 80.0 83.3 88.0 99.0205.0250.0250.0170.0
130.0125.0125.0125.0125.0125.0120.0125.0130.0140.0150.0120.0 98.0 98.0100.0
120.0110.0 99.5 96.0 91.0 88.0 90.0 97.0125.0200.0225.0200.0120.0 95.0 87.5
83.5 86.6 91.0100.0220.0300.0220.0160.0160.0160.0160.0160.0150.0150.0160.0
170.0180.0190.0
   2
WAVE REFRACTION USING SAMPLE DATA-OFF KOCHI.PERIOD= 5 SEC,DIR=240T
 2    5.0   1.0
23.0    15.0  -120.0
22.0    15.0  -120.0
WAVE REFRACTION USING SAMPLE DATA-OFF KOCHI.PERIOD= 5 SEC,DIR=300T
 2    5.0   1.0
13.0    15.0  - 60.0
12.0    15.0  - 60.0
```

APENDIX III SAMPLE OUT PUT

program parameters

grid limits absica = 38 ordinates = 36
printed outputinterval = 5point
grid size unit = 1853.00metres, deep water incremental step = .50grid units

WAVE REFRACTION USING SAMPLE DATA-OFF KOCHI.PERIOD= 5 SEC,DIR=240T
set no. 1 period = 5.00secs ray no = 1 time step = 118.73secs

POINT	x	y	ANGLE	DEPTH	MAX DIF	FIT	LENGTH	SPEED	HEIGHT	KR	KS
1	23.00	15.00	-120.00				39.02	7.80	1.00		
5	22.00	13.27	-120.00	34.16	.57	.11	39.02	7.80	1.00	1.0000	1.000
10	20.75	11.10	-120.00	28.61	.64	.11	39.02	7.80	1.00	1.0000	1.000
15	19.50	8.94	-120.00	22.59	1.72	.24	38.96	7.79	1.00	1.0000	.995
20	18.26	6.78	-119.87	16.49	1.19	.14	38.65	7.73	.98	.9998	.980
25	17.07	4.66	-118.12	8.75	6.14	.35	35.61	7.12	.92	.9908	.924
30	16.23	2.85	-109.93	1.64	35.70	.35	19.17	3.83	1.02	.9648	1.054
34	16.06	2.30	-103.74	.02	2891.31	.35	6.89	.45	1.64	.9702	1.691

ray stopped . skipped breaking condition due to coarse grid and reached shore.

WAVE REFRACTION USING SAMPLE DATA-OFF KOCHI.PERIOD= 5 SEC,DIR=240T
set no. 1 period = 5.00secs ray no = 2 time step = 118.73secs

POINT	x	y	ANGLE	DEPTH	MAX DIF	FIT	LENGTH	SPEED	HEIGHT	KR	KS
1	22.00	15.00	-120.00				39.02	7.80	1.00		
5	21.00	13.27	-120.00	32.87	.52	.14	39.02	7.80	1.00	1.0000	1.000
10	19.75	11.10	-120.00	27.14	.42	.08	39.02	7.80	1.00	1.0000	1.000
15	18.50	8.94	-120.00	21.66	2.56	.42	38.94	7.79	.99	1.0001	.994
20	17.26	6.78	-119.81	16.43	2.25	.24	38.64	7.73	.98	1.0002	.980
25	16.08	4.67	-118.20	8.29	6.07	.35	35.17	7.03	.91	.9909	.921
30	15.26	2.91	-110.16	1.34	27.30	.23	17.47	3.49	1.07	.9722	1.095
33	15.13	2.54	-106.61	.08	485.26	.23	8.70	.68	1.46	.9689	1.509

ray stopped . skipped breaking condition due to coarse grid and reached shore.

WAVE REFRACTION USING SAMPLE DATA-OFF KOCHI.PERIOD= 5 SEC,DIR=300T
set no. 2 period = 5.00secs ray no = 1 time step = 118.73secs

POINT	x	y	ANGLE	DEPTH	MAX DIF	FIT	LENGTH	SPEED	HEIGHT	KR	KS
1	13.00	15.00	-60.00				39.02	7.80	1.00		
5	14.00	13.27	-60.00	29.71	.46	.08	39.02	7.80	1.00	1.0000	1.000
10	15.25	11.10	-60.00	25.36	.31	.05	39.02	7.80	1.00	1.0000	1.000
15	16.50	8.94	-60.04	21.83	.89	.12	38.95	7.79	.99	.9998	.994
20	17.74	6.78	-60.34	16.62	2.22	.24	38.67	7.73	.98	.9970	.980
25	18.91	4.65	-62.89	9.44	6.61	.38	36.18	7.24	.91	.9838	.929
30	19.70	2.65	-76.71	5.01	9.90	.33	30.32	6.06	.88	.9556	.917
35	19.82	.85	-95.67	2.02	51.97	.70	25.19	4.21	.87	.9073	.956

ray stopped reached boundary. X = 19.82 Y = .85

WAVE REFRACTION USING SAMPLE DATA-OFF KOCHI.PERIOD= 5 SEC,DIR=300T
set no. 2 period = 5.00secs ray no = 2 time step = 118.73secs

POINT	x	y	ANGLE	DEPTH	MAX DIF	FIT	LENGTH	SPEED	HEIGHT	KR	KS
1	12.00	15.00	-60.00				39.02	7.80	1.00		
5	13.00	13.27	-60.00	29.61	.51	.11	39.02	7.80	1.00	1.0000	1.000
10	14.25	11.10	-60.00	25.60	1.69	.25	39.02	7.80	1.00	1.0000	1.000
15	15.50	8.94	-60.07	21.17	.93	.13	38.93	7.79	.99	.9998	.993
20	16.73	6.78	-60.55	16.09	3.87	.38	38.60	7.72	.97	.9950	.978
25	17.89	4.64	-63.39	9.10	5.91	.35	35.91	7.18	.90	.9660	.927
30	18.67	2.71	-75.99	3.41	17.55	.37	26.25	5.25	.85	.9039	.945
35	18.71	1.26	-101.88	1.35	41.39	.41	17.53	3.51	.91	.8311	1.094
37	18.59	.86	-112.92	.52	147.01	.49	15.18	2.24	.95	.8177	1.164

ray stopped reached boundary. X = 18.59 Y = .86

all sets completed ; no. of sets = 2