5 References

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Annex 1: Triangulation algorithm (for sub-sources division)

This annex includes the copy of the R-CRISIS source code routine used for the recursive division of the seismic sources with the geometry provided by the user into triangular sub-sources. Texts in green denote the comments included in the original source code (those in Spanish are translated to English in brackets).

A schematic explanation of this procedure can be found in Section 2.6.1 of this document.

```
Private Function AcomodaTriangulos(ByVal Plan As Short, ByVal xy(,) As Double, ByVal ixy3(,) As Short) As Triangulo()

  Dim I As Integer
  Dim Ntri As Integer = Me.Nver - 2
  Dim Tri(Ntri) As Triangulo
  Dim V1, V2, V3 As New PointType

  For I = 1 To Ntri

   Select Case Plan

    Case 1
     'Vertice 1 (Vertex 1)
     V1.x = xy(1, ixy3(1, I))
     V1.y = xy(2, ixy3(1, I))
     V1.z = xy(3, ixy3(1, I))
     'Vertice 2 (Vertex 2)
     V2.x = xy(1, ixy3(2, I))
     V2.y = xy(2, ixy3(2, I))
     V2.z = xy(3, ixy3(2, I))
     'Vertice 3 (Vertex 3)
     V3.x = xy(1, ixy3(3, I))
     V3.y = xy(2, ixy3(3, I))
     V3.z = xy(3, ixy3(3, I))

    Case 2
     'Vertice 1 (Vertex 1)
     V1.x = xy(1, ixy3(1, I))
     V1.z = xy(2, ixy3(1, I))
     V1.y = xy(3, ixy3(1, I))
     'Vertice 2 (Vertex 2)
     V2.x = xy(1, ixy3(2, I))
     V2.z = xy(2, ixy3(2, I))
     V2.y = xy(3, ixy3(2, I))
     'Vertice 3 (Vertex 3)
     V3.x = xy(1, ixy3(3, I))
     V3.z = xy(2, ixy3(3, I))
     V3.y = xy(3, ixy3(3, I))

    Case 3
     'Vertice 1 (Vertex 1)
     V1.y = xy(1, ixy3(1, I))
     V1.z = xy(2, ixy3(1, I))
     V1.x = xy(3, ixy3(1, I))
     'Vertice 2 (Vertex 2)
     V2.y = xy(1, ixy3(2, I))
     V2.z = xy(2, ixy3(2, I))
```

```
      V2.x = xy(3, ixy3(2, I))
      'Vertice 3 (Vertex 3)
      V3.y = xy(1, ixy3(3, I))
      V3.z = xy(2, ixy3(3, I))
      V3.x = xy(3, ixy3(3, I))

    End Select

    Tri(I) = New Triangulo()
    Tri(I) = Triangulo.LlenaConVertices(V1, V2, V3)

  Next I

  Return Tri

End Function

Function Triangulate(ByRef errMsg As ArrayList, Optional ByRef Plano As Short = 0) As Triangulo()

  errMsg = New ArrayList
  Plano = 0

  If Me.Nver < 3 Then
    errMsg.Add("Polygon has too few vertex")
    Return Nothing
  End If

  Dim ms As String = ""
  Dim Tr() As Triangulo

  Tr = Me.TriangulateInPlane(1, ms)
  If Not IsNothing(Tr) Then
    errMsg.Clear()
    Plano = 1
    Return Tr
  Else
    errMsg.Add("In plane XY: " & ms)
  End If

  Tr = Me.TriangulateInPlane(2, ms)
  If Not IsNothing(Tr) Then
    errMsg.Clear()
    Plano = 2
    Return Tr
  Else
    errMsg.Add("In plane XZ: " & ms)
  End If

  Tr = Me.TriangulateInPlane(3, ms)
  If Not IsNothing(Tr) Then
    errMsg.Clear()
    Plano = 3
    Return Tr
  Else
    errMsg.Add("In plane YZ: " & ms)
    Plano = 0
    Return Nothing
  End If

End Function
```

```
Private Function TriangulateInPlane(ByVal IPlano As Short, ByRef errMsg As String) As Triangulo()

 errMsg = ""

 'Muy pocos vértices (Too few vertexes)
 If Me.Nver < 3 Then
  errMsg = "Polygon has too few vertex"
  Return Nothing
 End If

 Dim PolProv As New Poligono(Me.Nver)
 PolProv.IgualaCon(Me)
 For i As Integer = 1 To Me.Nver
  Dim xx, yy, zz As Double
  Select Case IPlano
   Case 1
    'Plano X-Y (X-Y plane)
    xx = PolProv.mvarVertice(i).x
    yy = PolProv.mvarVertice(i).y
    zz = PolProv.mvarVertice(i).z
   Case 2
    'Cambiamos al plano X-Z (Change to X-Z plane)
    xx = PolProv.mvarVertice(i).x
    yy = PolProv.mvarVertice(i).z
    zz = PolProv.mvarVertice(i).y
   Case 3
    'Cambiamos al plano Y-Z (Change to X-Z plane)
    xx = PolProv.mvarVertice(i).y
    yy = PolProv.mvarVertice(i).z
    zz = PolProv.mvarVertice(i).x
  End Select
  PolProv.SetVertex(i, New PointType(xx, yy, zz))
 Next i

 'Verificamos que los bordes no se crucen (Verification that borders do not cross among them)
 If PolProv.IsComplex(errMsg, 0, False) Then Return Nothing

 'Si no se cruzan, Ponemos el orden correcto (If they do not cross are arranged in the proper order)
 PolProv.PonSentido(TipoSentido.CounterClockWise)

 'Verificamos que no sean colineales en este plano (Verification that vertexes are not colineal in this plane)
 'Simplemente calculamos el área: (Its area is calculated)
 Dim Am As Double = PolProv.Area(False)
 'La comparamos con el área de su boundingBox (It is compared with the area of its boundingBox)
 Dim AmBB As Double = PolProv.AreaXYOfBounds

 If AmBB > 0 Then
  If Am / AmBB <= 0.00000001 Then
   errMsg = "Polygon has null area in this plane"
   Return Nothing
  End If
 Else
  errMsg = "Polygon has null area in this plane"
  Return Nothing
 End If

 'Divide en triángulos (Division into triangles)
 Dim Xy(3, Me.Nver) As Double
 Dim Ixy(Me.Nver) As Short
```

```
    Dim Ixy3(3, Me.Nver) As Short
    For i As Short = 1 To CShort(Me.Nver)
      Xy(1, i) = PolProv.Vertice(i).x
      Xy(2, i) = PolProv.Vertice(i).y
      Xy(3, i) = PolProv.Vertice(i).z
      Ixy(i) = i
    Next i
    Dim M As Integer
    Call Deldivide(CShort(Me.Nver), Ixy, Xy, M, Ixy3)
    Return Me.AcomodaTriangulos(IPlano, Xy, Ixy3)

  End Function

  ''' <summary>
  ''' Determines if a polygon is complex or not
  ''' </summary>
  ''' <param name="errMsg">Input: nothing; output: contains the reasons why a given polygon is complex</param>
  ''' <param name="Tolerance">Parameter that indicates how close two points have to be in order to be considered
the same. The distance is Tolerance*Polygon Perimeter</param>
  ''' <returns>True if the polygon is comples, False if the polygon is simple</returns>
  ''' <remarks></remarks>
  Public Function IsComplex(ByRef errMsg As String, Optional Tolerance As Double = 0, Optional checkAlsoZ As
Boolean = False) As Boolean

    errMsg = ""
    Dim Tol As Double = Tolerance * Me.Perimetro
    'Tol = 0
    'checkAlsoZ = False

    'Verificamos que no haya vértices iguales (Verification that there are not equal vertexes)
    For I As Integer = 1 To Me.Nver
      For J As Integer = I + 1 To Me.Nver
        Dim Delta As PointType = Me.Vertice(I) - Me.Vertice(J)
        Dim Dx As Double = Math.Abs(Delta.x)
        Dim Dy As Double = Math.Abs(Delta.y)
        Dim Dz As Double = Math.Abs(Delta.z)
        If checkAlsoZ Then
          If Dx <= Tol And Dy <= Tol And Dz <= Tol Then errMsg = errMsg & "Vertex " & I & " and " & J & " are the same"
& vbCrLf
        Else
          If Dx <= Tol And Dy <= Tol Then errMsg = errMsg & "Vertex " & I & " and " & J & " are the same" & vbCrLf
        End If
      Next
    Next I
    If errMsg <> "" Then Return True

    'Creamos segmentos (Segments are created)
    Dim NSeg As Integer = Me.Nver
    Dim Seg(NSeg) As Segmento
    For I As Integer = 1 To Me.Nver
      Dim J As Integer = I + 1
      If J > Me.Nver Then J = 1
      Seg(I) = New Segmento(Me.Vertice(I), Me.Vertice(J))
    Next I

    'Barremos segmentos (Segments are transited)
    For I As Integer = 1 To NSeg
      For J As Integer = I + 1 To NSeg
        If Segmento.TheseSegmentsCross(Seg(I), Seg(J)) Then errMsg = errMsg & "Segments " & I & " and " & J & "
intersect" & vbCrLf
```

```
    Next J
  Next I

  If errMsg = "" Then
    Return False
  Else
    Return True
  End If

End Function


 Public Sub Circum(ByRef x1 As Double, ByRef y1 As Double, ByRef x2 As Double, ByRef y2 As Double, ByRef x3 As
Double, ByRef y3 As Double, _
        ByRef xo As Double, ByRef yo As Double, ByRef rsq As Double)

  Dim sx13, sy13 As Double
  Dim dx13, dy13 As Double
  Dim sx12, sy12 As Double
  Dim dx12, dy12 As Double
  Dim Den As Double
  Dim xfac1, xfac2 As Double
  Dim yfac1, yfac2 As Double
  Dim xnum, ynum As Double
  Dim dx20, dx10, dx30 As Double
  Dim dy20, dy10, dy30 As Double
  Dim rsq2, rsq1, rsq3 As Double

  xo = -999.0
  yo = -999.0
  rsq = -999.0
  sx13 = (x1 + x3) / 2
  sy13 = (y1 + y3) / 2
  dx13 = (x3 - x1)
  dy13 = (y3 - y1)
  sx12 = (x1 + x2) / 2
  sy12 = (y1 + y2) / 2
  dx12 = (x2 - x1)
  dy12 = (y2 - y1)
  Den = (dx13 * dy12) - (dx12 * dy13)

  'No puede cuando los puntos son colneales (It is not possible if vertexes are colineal)
  If (Den = 0) Then Exit Sub

  xfac1 = (sy13 * dy13) + (sx13 * dx13)
  xfac2 = (sy12 * dy12) + (sx12 * dx12)
  yfac1 = (sx13 * dx13) + (sy13 * dy13)
  yfac2 = (sx12 * dx12) + (sy12 * dy12)
  xnum = (xfac1 * dy12) - (xfac2 * dy13)
  ynum = (yfac1 * dx12) - (yfac2 * dx13)

  xo = xnum / Den
  yo = -ynum / Den
  dx10 = x1 - xo
  dx20 = x2 - xo
  dx30 = x3 - xo
  dy10 = y1 - yo
  dy20 = y2 - yo
  dy30 = y3 - yo
  rsq1 = (dx10 * dx10) + (dy10 * dy10)
```

```
  rsq2 = (dx20 * dx20) + (dy20 * dy20)
  rsq3 = (dx30 * dx30) + (dy30 * dy30)
  rsq = rsq1

 End Sub

 Friend Sub Delaunay(ByRef N As Integer, ByRef Ixy() As Short, ByRef xy(,) As Double, ByRef j1 As Short, ByRef j2
As Short, _
        ByRef j3 As Short, ByRef idel As Short)

  Dim xj2, xj1, xj3 As Double
  Dim yj2, yj1, yj3 As Double
  Dim dx31, dx23, dx12 As Double
  Dim sx31, sx23, sx12 As Double
  Dim dy31, dy23, dy12 As Double
  Dim sy31, sy23, sy12 As Double
  Dim term2, term1, term3 As Double
  Dim y0, Area, x0, rsq As Double
  Dim k, kj As Integer
  Dim dY, dX, r2 As Double


  xj1 = xy(1, j1)
  xj2 = xy(1, j2)
  xj3 = xy(1, j3)
  yj1 = xy(2, j1)
  yj2 = xy(2, j2)
  yj3 = xy(2, j3)

  dx23 = xj3 - xj2
  dx31 = xj1 - xj3
  dx12 = xj2 - xj1
  sx23 = xj3 + xj2
  sx31 = xj1 + xj3
  sx12 = xj2 + xj1

  dy23 = yj3 - yj2
  dy31 = yj1 - yj3
  dy12 = yj2 - yj1
  sy23 = yj3 + yj2
  sy31 = yj1 + yj3
  sy12 = yj2 + yj1

  term1 = (dx23 * sy23) - (dy23 * sx23)
  term2 = (dx31 * sy31) - (dy31 * sx31)
  term3 = (dx12 * sy12) - (dy12 * sx12)

  Area = -(term1 + term2 + term3) / 4

  If (Area < 0) Then idel = 5
  If (Area = 0) Then idel = 4
  If (Area > 0) Then idel = 3

  Call Circum(xj1, yj1, xj2, yj2, xj3, yj3, x0, y0, rsq)

  If (idel > 3) Then Exit Sub

  If (rsq = -999) Then GoTo 30

  For k = 1 To N
```

```
    kj = Ixy(k)
    If (xy(1, kj) = xy(1, j1) And xy(2, kj) = xy(2, j1)) Then GoTo 10
    If (xy(1, kj) = xy(1, j2) And xy(2, kj) = xy(2, j2)) Then GoTo 10
    If (xy(1, kj) = xy(1, j3) And xy(2, kj) = xy(2, j3)) Then GoTo 10
    dX = xy(1, kj) - x0
    dY = xy(2, kj) - y0
    r2 = (dX * dX) + (dY * dY)

    If (r2 - rsq) < -0.00001 Then GoTo 30
    If (r2 = rsq) Then
     idel = 2
    End If
10:
   Next k

   idel = 1
   Exit Sub

30:
   idel = 3
   Exit Sub

  End Sub

  Public Sub Deldivide(ByRef N As Short, ByRef Ixy() As Short, ByRef xy(,) As Double, ByRef m As Integer, ByRef
ixy3(,) As Short)

   Dim i, ii As Integer

   m = 0
   For i = N To 3 Step -1
    ii = i
    m = m + 1
    Call Delsplit(ii, Ixy, xy, ixy3, m)
   Next i

  End Sub

  Friend Sub Delsplit(ByRef N As Integer, ByRef Ixy() As Short, ByRef xy(,) As Double, ByRef ixy3(,) As Short, ByRef
Ncol As Integer)

   Dim j3, j1, j2, j As Integer
   Dim ixyj1 As Short
   Dim ixyj2 As Short
   Dim ixyj3 As Short
   Dim ielim1 As Short
   Dim ielim2 As Short
   Dim ielim3 As Short
   Dim idel As Short

   If (N = 3) Then

    ixy3(1, Ncol) = Ixy(1)
    ixy3(2, Ncol) = Ixy(2)
    ixy3(3, Ncol) = Ixy(3)
    Ixy(1) = 0
    Ixy(2) = 0
    Ixy(3) = 0
    N = 0
```

```
 Else

  For j2 = 1 To N
   j1 = j2 - 1
   If (j1 <= 0) Then j1 = j1 + N
   j3 = j2 + 1
   If (j3 > N) Then j3 = j3 - N
   ixyj1 = Ixy(j1)
   ixyj2 = Ixy(j2)
   ixyj3 = Ixy(j3)
   Call Delaunay(N, Ixy, xy, ixyj1, ixyj2, ixyj3, idel)
   If (idel = 1 Or idel = 2) Then
    ielim1 = Ixy(j1)
    ielim2 = Ixy(j2)
    ielim3 = Ixy(j3)
    ixy3(1, Ncol) = Ixy(j1)
    ixy3(2, Ncol) = Ixy(j2)
    ixy3(3, Ncol) = Ixy(j3)
    For j = j2 To N - 1
     Ixy(j) = Ixy(j + 1)
    Next j
    Ixy(N) = 0
    N = N - 1
    Exit Sub
   End If
  Next j2

 End If

End Sub
```

Annex 2: Supplementary information and datasets

The following files are included in the electronic supplement from which the seismic hazard model developed in Chapter 3 can be reconstructed:

- Reference map: Island_Contour.shp
- Reference cities: Cities.asc
- Digital elevation model: Capra Island DEM.grd
- Seismic microzonation: Microzonation.grd and Microzonation.ft
- Spectral ordinates: Spectral_ordinates.xlsx
- Seismicity parameters: Seismicity_parameters.xlsx
- Gridded seismicity parameters:
    - Lo.grd
    - EB.grd
    - MU.grd
- Geometry of seismic sources: Sources_geometry.xlsx
- Output files:
    - *.res: Capra Island.res
    - *.gra: Capra Island.gra
    - *.fue: Capra Island_cities.fue
    - *.map: Capra Island_cities.map
    - *.des: Capra Island_cities.des