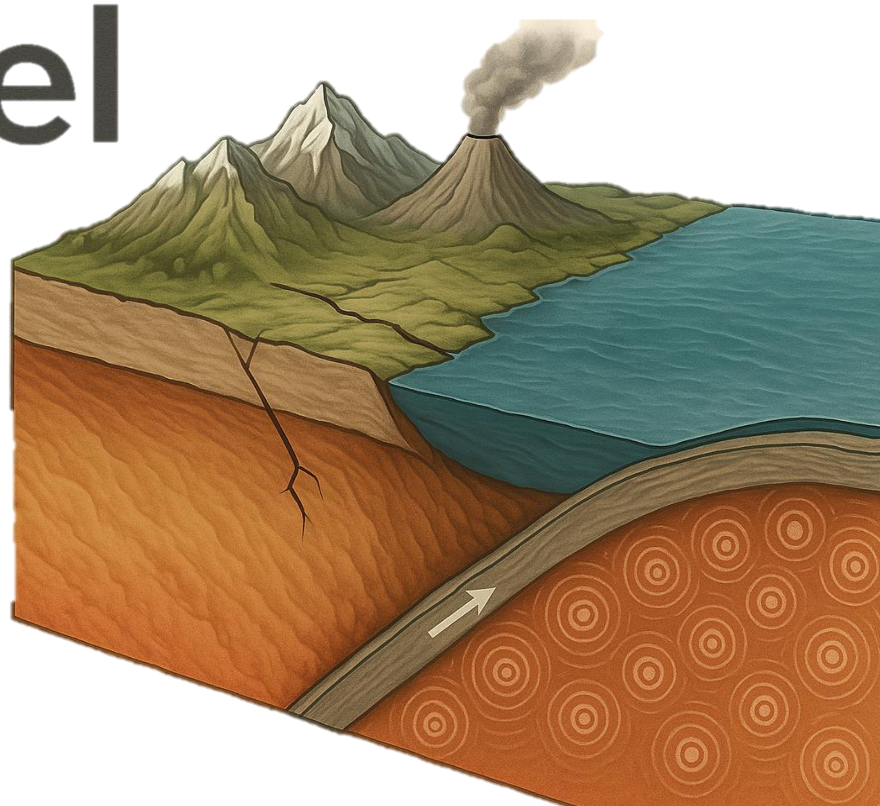
Universidad Politécnica de Madrid (UPM)
Escuela Técnica Superior de Ingenieros en Topografía, Geodesia y Cartografía
Grupo de Investigación de Ingeniería Sísmica (GIIS)

User Manual
HybridModel (${}^{H}{}_{M}$) TOOL
Version 1.0

July 2025



Written by:

Carlos Gamboa-Canté
Alicia Rivas-Medina
María Belén Benito

Executed from Python

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HOW TO IMPLEMENT THIS CODE

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0. Software and Tools Installation

Before running HybridModel Tool, ensure that all necessary software and dependencies are installed:

0.1 Install Python

- Download and install **Python** from "[Download Python]".

0.20.2 Enter the *HybridModel* folder

Enter the Command Prompt and go to the path where the *HybridModel* folder is located.

0.3 Install Required Python Packages

Run the following script in the command line to install all necessary packages:

```
> python 0_Install_Packages.py
```

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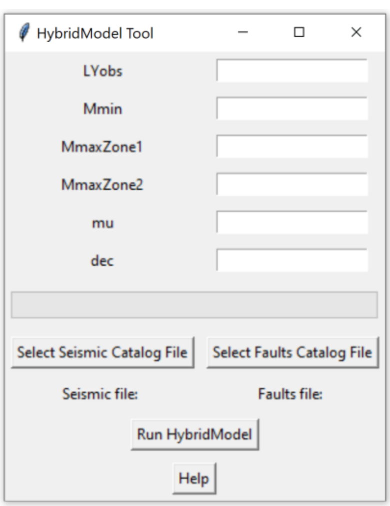
1. Execute the HybridModel Tool

Run the **HybridModel Tool** using the script `1_HybridModel_Tool.py`

1.1Setting input parameters

The following graphical interface will be displayed, in which the input parameters and the seismic catalog and fault catalog files must be entered:

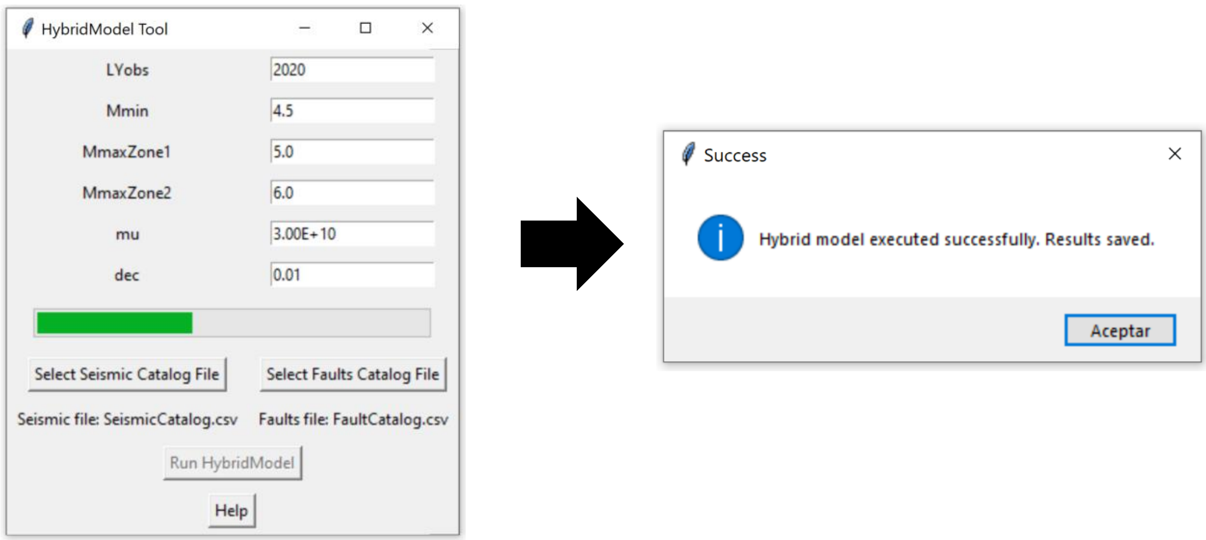


LYobs: Last year of registration in the seismic catalog.
Mmin: Minimum magnitude for seismic distribution (Mw).
MmaxZone1: Lower limit for the maximum magnitude of the zone (Mw).
MmaxZone2: Upper limit for the maximum magnitude of the zone (Mw).
mu: rigidity modulus (Pa) (it is recommended to use 3.00E+10).
dec: precision for the b-value (NOTE: for small values of precision the calculation times will take longer).

The **Seismic Catalog** and **Fault Catalog** files must be in ***comma-separated*** values (CSV) format (,). For more information, please refer to the **Help button**.

1.2 Run HybridModel

After entering the input parameters, press the "**Run HybridModel**" button and the program will begin calculating the seismic parameters. A progress bar will appear, indicating that the program is performing the calculations. Upon completion, a message will appear indicating that the different combinations of results have been generated.



1.3 Visualization of the different combinations

Upon completion of the calculations, a csv file will be generated with the different combinations for the parameters MmaxC, btf, brz, and MmaxZone. To view these results, open the file `Output_HM.csv`.

ID	MmaxC	btf	btz	MmaxZone
1	5.5	1.01	2.27	5
2	5.5	1.03	2.44	5
3	5.5	1.05	2.62	5
4	5.5	1.07	2.81	5
5	7.7	1.07	1.78	5.9
6	7.7	1.13	1.36	5.8
7	7.7	1.15	1.67	5.9
8	7.7	1.18	1.27	5.8
9	7.7	1.2	1.23	5.8
10	7.7	1.21	1.21	5.8
11	7.7	1.22	1.55	5.9
12	7.7	1.25	1.49	5.9
13	7.7	1.26	1.76	6
14	7.7	1.29	1.7	6
15	7.7	1.33	1.61	6
16	7.7	1.34	1.27	5.9
17	7.7	1.36	1.21	5.9
18	7.7	1.49	1.06	6
19	7.7	1.5	1.01	6

ID: ID Number of the combination.

MmaxC: Maximum magnitude of Completeness.

btf: β-value for the fault-type sources.

btz: β-value for the zone-type source.

MmaxZone: Maximum magnitude for the zone-type source.

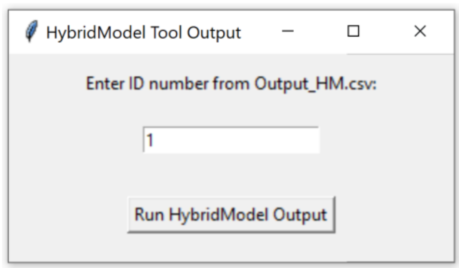
2. Export source models files

Run the second part of the ***HybridModel*** using the following script:

```
> python 2_HybridModel_Output_Sources.py
```

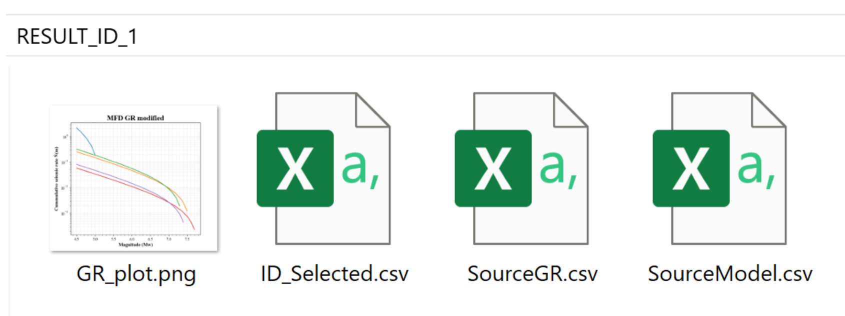
2.1 Select ID number combination

When running this script, a window will appear asking to enter the **ID number** of the combination for which want to export the source model. This **ID number** must be selected according to the combination listed in the `Output_HM.csv file`. The output files will then be generated by pressing the "**Run HybridModel Output**" button.



2.2 Visualization of the output files

A folder named `RESULT_ID_#` will be generated, containing the seismic source files created according to the selected ID number.



GR_plot.png: A graph is generated that shows the Gutenberg-Richter modified model for the zone-type source and faults-type sources.

ID_Selected.csv: It contains the parameters MmaxC, btf, btz, and MmaxZone of the combination selected in Output_HM.csv.

SourceGR.csv: This file contains the values of the maximum magnitude (Mmax), the accumulated seismic rate for the minimum magnitude ($\dot{N}$Mmin), the β-value, the b-value, and the a-value for the zone-type source and faults-type sources.

SourceModel.csv: This file contains the accumulated seismic rates [$\dot{N}$(m)] in the range of Mmin to Mmax for the zone-type source and faults-type sources.

Executed from R-studio

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📌 HOW TO IMPLEMENT THIS CODE

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0. Software and Tools Installation

Before running the **HybridModel Tool**, ensure that all necessary software and dependencies are installed:

0.1 Install R and RStudio

- Download and install **R** from CRAN.
- Download and install **RStudio** from Posit.

0.2 Install Rtools (Windows Users Only)

For Windows users, **Rtools** is required to compile some R packages:

- Download **Rtools** from CRAN Rtools.

0.3 Install Required R Packages

Run the following script in **RStudio** to install all necessary packages:

`Install_Packages.r`

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1. Execute the HybridModel Tool

Run the **HybridModel Tool** using the script `HybridModel.r`.

1.1 Run the HybridModelBalancing() Function First

This generates necessary intermediate outputs before running the main analysis

1.2 Run the HybridModelSources() Function Sequentially

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2. Apply HybridModel in the Study Region

Use the script `Run_HybridModels.r`, which contains two examples demonstrating how to execute the code.

2.1 Set Up the Working Directory

Before running the **HybridModel Tool**, define the working directory where input files are stored:

```
setwd("C:/Users/.../Guatemala/")  # Replace with the actual path
```

Ensure that the directory contains the input files:

- **SeismicCatalog.csv**
- **FaultCatalog.csv**

The **Seismic Catalog** and **Fault Catalog** files must be in ***semicolon-separated*** values (CSV) format (;).

2.2 Define Input Data and Execute the Commands

For example, if analyzing **Guatemala** and **Granada**, repeat the process for each region.

This guide provides a structured workflow to ensure smooth execution of the **HybridModel Tool**. Follow each step carefully to avoid errors and obtain results.

Detail of the *HybridModel* ($^{H}{}_{M}$) formulation

$$\int_a^b f(x)dx$$

This section contains additional information describing the iterative process of the code applied in the *HybridModel* ($^{H}{}_{M}$). The way the code works is as follows:

<u>STEP 0:</u> Calculation vectors

Calculation vectors are created for the parameters *MmaxC*, *MmaxZone*, *btf* y *btz*. The increment of these vectors depends on the precision assigned in the *dec* parameter. For the *MmaxC* vector, the limits are from *Mmin*+1.0 – *Mmax obs*. For the *MmaxZone* vector, the limits are user-defined from *MmaxZone1* – *MmaxZone2*. Finally, for the *btf* y *btz* vectors, the limits of the $\beta - values$ range from 1.0 – 3.0 (these can be modified by the user if the seismotectonic context of the region is known).

(1) $MmaxC = [M_{min} + 1.0, \dots, M_{max\ obs}]$
(2) $MmaxZone = [MmaxZone1, \dots, MmaxZone2]$
(3) $btf, btz = [1.0, \dots, 3.0]$

<u>STEP 1:</u> Seismic moment ($\mathbf{M_o}$) and moment rate ($\mathbf{\dot{M}_o}$) in the seismic catalog in the range Mmin to Mmaxobs

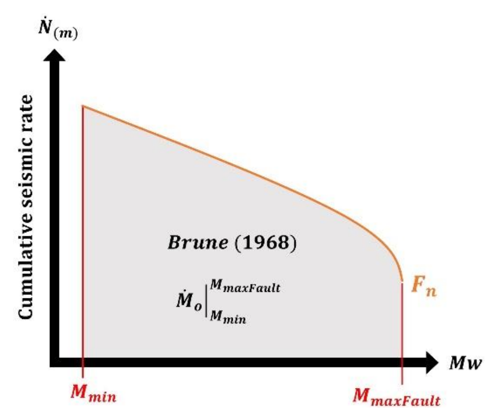
The seismic moment (M_o) and moment rate ($\dot{M}_o$) are calculated for each bin of magnitude (m) from *Mmin* to *Mmax obs*. This is done for the completeness periods $[CY(m)]$.

(1) $M_o(m) = 10^{(16.1+1.5\cdot m)} \rightarrow Hanks\ and\ Kanamori\ (1979)$
(2) $\dot{n}(m) = \frac{n(m)}{LY_{obs} - CY_n}$
(3) $\dot{M}_o = \dot{n}(m) \cdot M_o\ (m)$

<u>STEP 2:</u> Seismic moment ($\mathbf{M_{o\ M_{maxFault}}}$) and moment rate ($\mathbf{\dot{M}_{o\ fault}}$) for faults in the range Mmin to MmaxFault

The seismic moment ($M_{o\ fault}$) and moment rate ($\dot{M}_{o\ fault}$) for the fault-type sources are calculated from *Mmin* to *MmaxFault*.

(1) $M_{o\ M_{maxFault}} = 10^{(16.1+1.5\cdot M_{maxFault})} \rightarrow Hanks\ and\ Kanamori\ (1979)$
(2) $\dot{M}_{o\ fault} = \dot{u} \cdot A \cdot \mu \rightarrow Brune\ (1968)$

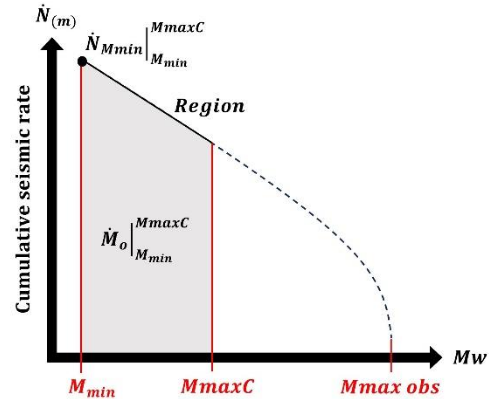


<u>STEP 3:</u> Cumulative seismic rate Mmin ($\dot{\mathbf{N}}_{\boldsymbol{M_{min\,region}}}$) and moment rate ($\dot{\mathbf{M}}_{\boldsymbol{o\,region}}$) for the region in the range Mmin to MmaxC

Cumulative seismic rate *Mmin* ($\dot N_{M_{min\,region}}$) and moment rate ($\dot M_{o\,region}$) for the region is calculated from *Mmin* to *MmaxC*.

(1) $\dot N_{M_{min\,region}}\Big|_{M_{min}}^{M_{maxC}} = \sum_{M_{min}}^{M_{maxC}} \dot n(m)$

(2) $\dot M_{o\,region}\Big|_{M_{min}}^{M_{maxC}} = \sum_{M_{min}}^{M_{maxC}} \dot n(m) \cdot M_o(m)$

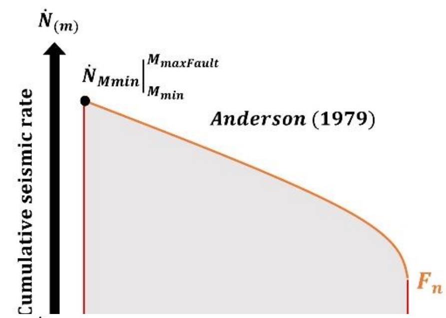


<u>STEP 4:</u> Cumulative seismic rate ($\dot{\mathbf{N}}_{\boldsymbol{M_{min\,fault}}}$) and moment rate ($\dot{\mathbf{M}}_{\boldsymbol{o\,fault}}$) for each fault in the range Mmin to MmaxC

Cumulative seismic rate *Mmin* ($\dot N_{M_{min\,fault}}$) and moment rate ($\dot M_{o\,fault}$) for fault-type source are calculate from *Mmin* to *MmaxC*.

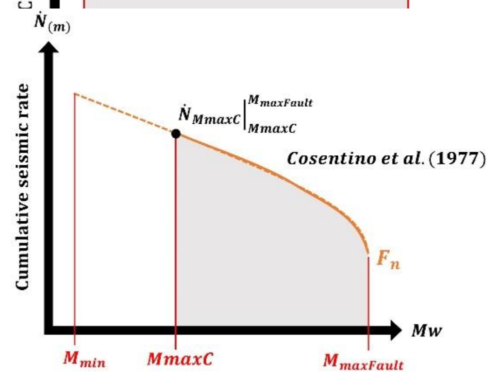
(1) $\dot N_{M_{min}}\Big|_{M_{min}}^{M_{maxFault}} = \dfrac{\dot M_{o\,fault}\cdot(\bar d - btf)\cdot\left[e^{-btf(M_{min})}-e^{-btf(M_{maxFault})}\right]}{btf\cdot\left[e^{-btf(M_{maxFault})}\cdot Mo_{M_{maxFault}}-e^{-btf(M_{min})}\cdot Mo_{M_{min}}\right]}$

↳ $Anderson$ (1979)

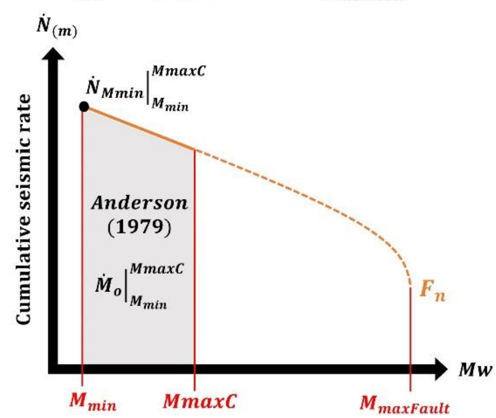


(2) $\dot N_{M_{maxC}}\Big|_{M_{maxC}}^{M_{maxFault}} = \dot N_{M_{min}}\Big|_{M_{min}}^{M_{maxFault}} \cdot \left[\dfrac{e^{-btf(M_{maxC})}-e^{-btf(M_{maxFault})}}{e^{-btf(M_{min})}-e^{-btf(M_{maxFault})}}\right]$

↳ $Cosentino\ et\ al.$ (1977)



(3) $\dot N_{M_{min\,fault}}\Big|_{M_{min}}^{M_{maxC}} = \dot N_{M_{min}}\Big|_{M_{min}}^{M_{maxFault}} - \dot N_{M_{maxC}}\Big|_{M_{maxC}}^{M_{maxFault}}$



$$\dot{M}_{o\,fault}\Big|_{M_{min}}^{M_{maxC}} = \frac{\dot{N}_{M_{min\,fault}}\Big|_{M_{min}}^{M_{maxC}} \cdot btf \cdot \left[e^{-btf(M_{maxC})} \cdot Mo_{M_{maxC}} - e^{-btf(M_{min})} \cdot Mo_{M_{min}}\right]}{(\bar{d} - btf) \cdot \left[e^{-btf(M_{min})} - e^{-btf(M_{maxC})}\right]}$$

↳ $Anderson$ (1979)

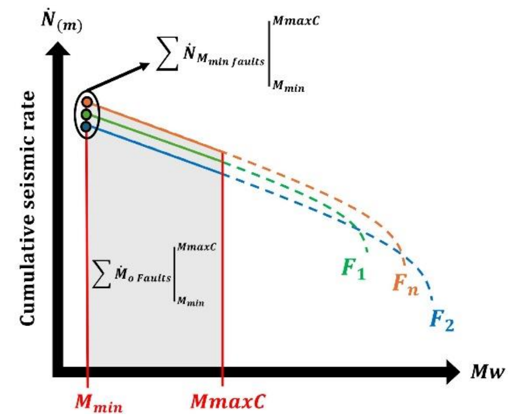
<u>STEP 5:</u> Total cumulative seismic rate ($\boldsymbol{\Sigma\dot{N}_{M_{min\,fault}}}$) and moment rate ($\boldsymbol{\Sigma\dot{M}_{o\,fault}}$) for all faults in the range Mmin to MmaxC

Total cumulative seismic rate *Mmin* ($\Sigma\dot{N}_{M_{min\,fault}}$) and total moment rate ($\Sigma\dot{M}_{o\,fault}$) for the fault-type sources are calculated from *Mmin* to *MmaxC*.

(1)

$$\sum \dot{N}_{M_{min\,Faults}}\Big|_{M_{min}}^{M_{maxC}} = \dot{N}_{M_{min\,f_1}}\Big|_{M_{min}}^{M_{maxC}} + \dot{N}_{M_{min\,f_2}}\Big|_{M_{min}}^{M_{maxC}} + \cdots + \dot{N}_{M_{min\,f_n}}\Big|_{M_{min}}^{M_{maxC}}$$

$$\sum \dot{M}_{o\,Faults}\Big|_{M_{min}}^{M_{maxC}} = \dot{M}_{o\,f_1}\Big|_{M_{min}}^{M_{maxC}} + \dot{M}_{o\,f_2}\Big|_{M_{min}}^{M_{maxC}} + \cdots + \dot{M}_{o\,f_n}\Big|_{M_{min}}^{M_{maxC}}$$



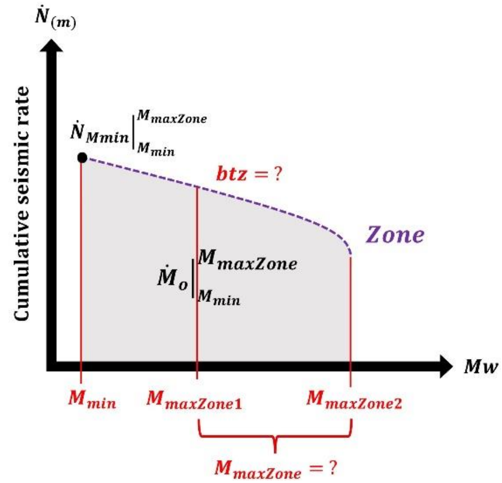
<u>STEP 5:</u> Cumulative seismic rate ($\dot{N}_{M_{min\,zone}}$) and moment rate ($\dot{M}_{o\,zone}$) for the zone in the range Mmin to MmaxZone

Cumulative seismic rate *Mmin* ($\dot{N}_{M_{min\,zone}}$) and moment rate ($\dot{M}_{o\,zone}$) for the zone-type source are calculated from *Mmin* to *MmaxZone*.

(1)

$$\dot{N}_{M_{\min zone}}\Big|_{M_{min}}^{M_{maxZone}} = \dot{N}_{M_{\min region}}\Big|_{M_{min}}^{M_{maxC}} - \sum \dot{N}_{M_{\min Faults}}\Big]_{M_{min}}^{M_{maxC}}$$

$$\dot{M}_{o\,zone}\Big|_{M_{min}}^{M_{maxZone}} = \dot{M}_{o\,region}\Big|_{M_{min}}^{M_{maxC}} - \sum \dot{M}_{o\,Faults}\Big]_{M_{min}}^{M_{maxC}}$$



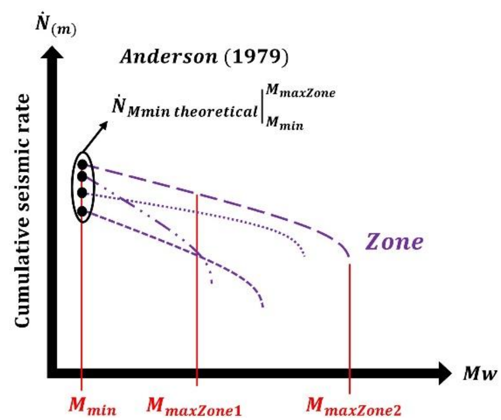
<u>STEP 7:</u> The theoretical cumulative seismic rate ($\dot{N}_{M_{min\,theoretical}}$) for the zone in the range Mmin to MmaxZone

The theoretical cumularive seismic rate *Mmin* ($\dot{N}_{M_{min\,theoretical}}$) for the zone-type source is calculated from *Mmin* to *MmaxZone*.

(1)

$$\dot{N}_{M_{min\,theoretical}} = \frac{\dot{M}_{o\,zone}\Big|_{M_{min}}^{M_{maxZone}} \cdot (\bar{d} - btz) \cdot \left[e^{-btz(M_{min})} - e^{-btz(M_{maxZone})}\right]}{btz \cdot \left[e^{-btz(M_{maxZone})} \cdot Mo_{maxZone} - e^{-btz(M_{min})} \cdot Mo_{M_{min}}\right]}$$

↳ $Anderson$ (1979)



***STEP 8:** Acceptance tolerance and required conditions for obtaining a coherent result*

The tolerance of the theoretical value and the observed value, as well as the conditions imposed to maintain system equilibrium (zone + faults), are verified. If the established conditions are met, the code will store the combination *MmaxC, btf, btz*, and *MmaxZone* that maintains the system in equilibrium. Otherwise, the iterative process restarts, taking other values from the vectors *MmaxC, btf, btz*, and *MmaxZone*.

(1) $Dif_{\dot{N}_{Mmin}} = \dot{N}_{M_{\min zone}}\Big|_{M_{min}}^{M_{maxZone}} - \dot{N}_{M_{min\ theoretical}}$

(2) $Dif_{\dot{N}_{Mmin}} < 0.001$

$\dot{N}_{M_{\min zone}}\Big|_{M_{min}}^{M_{maxZone}} > 0$

$\dot{M}_{o\ zone}\Big|_{M_{min}}^{M_{maxZone}} > 0$

Generate all the possible solutions:

ID	**MmaxC**	***btf***	***btz***	**Mmax zone**
1	$MmaxC_1$	btf_1	btz_1	$Mmax_1$
2	$MmaxC_2$	btf_2	btz_2	$Mmax_2$
3	$MmaxC_3$	btf_3	btz_3	$Mmax_3$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
n	$MmaxC_n$	btf_n	btz_n	$Mmax_n$

The following flowchart details the formulation previously described: