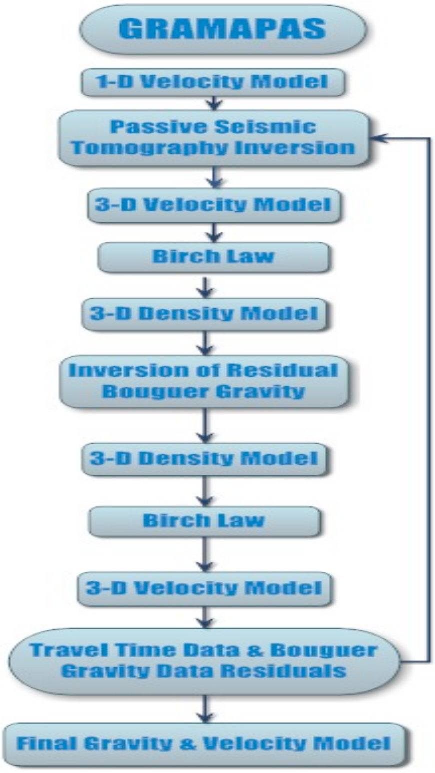
GRAMAPAS®

Joint Inversion of Passive Seismic Tomography and Gravity Measurements

LandTech has developed **GRAMAPAS®** a joint Passive Seismic Data and Bouguer gravity residuals inversion. It consists of the reiteration of a set of *n* iterations of the seismological inversion, leading to a new velocity model and new event locations, followed by one inversion of the gravity data and the computation of a new density contrast model. This procedure is repeated until the convergent criterion is satisfied.

Using this method, it is possible to estimate qualitatively what information is brought to the model by seismic and gravity data. The flow chart below illustrates the organization of the sequential method.



The starting velocity model used for the first inversion of traveltime data is the initial 1-D velocity model estimated from the geological characteristics of the region under investigation. Then, the iterative PATOS® program calculates the 3-D V_p model and new earthquake locations from the arrival times of local earthquakes. This process is stopped after *n* iterations.

This 3-D absolute V_p model is then converted into a 3-D relative density contrast model using Birch's law. At this stage, the linear inverse gravity problem is solved leading to a new density contrast model that is transformed back to a new V_p model. This completes the first loop of the sequential inversion.

The following loops use the same procedure defining as input the final velocity model of the previous loop. The sequential process is stopped when the standard deviations between observed data and theoretical values calculated from the models stop decreasing significantly between two loops.

The density contrast model is computed using the linear stochastic method. After dividing the crustal model into prisms, the linear equation of the forward problem has the matrix form

$$\mathbf{G p_o = d_o}$$

$\mathbf{p_o}$ is the *a priori* density contrast model determined from the Passive Seismic Tomography model. We define **G** as the matrix of the forward problem, where element $G_{i\,j}$ is the residual gravity field at point i induced by cell j with unit density.

We assume that the measurement errors in the residual gravity field are independent and define a diagonal covariance matrix on the experimental gravity errors. We also assume an uncertainty on the *a priori* density contrast solution by a covariance matrix, the terms of which are given by

where

$$\Lambda_{ij} = c\sigma_i\,\sigma_j$$

From a stochastic point of view, this *a priori* covariance matrix ($C_{i\,j}$) could be deduced from the *a posteriori* covariance matrix of the velocity model. If the *a posteriori* uncertainty on V_p is high, σ_i is also high, so the density value in cell i can vary strongly during the gravity inversion.

Conversely, if the *a posteriori* uncertainty on V_p is low, indicating that the V_p value is well constrained in the cell i, σ_i is low, which prohibits strong variations of the density contrast in the cell.

The data sets are complementary because gravity data provide information where seismological data are sparse. $\Lambda_{i\,j}$ is the product of the standard deviations σ_i and σ_j of the density contrast in prisms i and j deduced from the *a posteriori* standard deviation of the V_p model and c is a damping factor.

d_{ij} is the distance between cells i and j, and λ is the correlation radius of the model, the parameters c and λ are chosen in order to significantly decrease the standard deviations between observed gravity and traveltime data and theoretical values computed from density and V_p models in the iterative process.

The factor c is assumed to range from 0 to 1. When it is close to 0, the weight of the gravity data is weak in the cooperative inversion and the final model will be the initial mode. When c is close to 1, the V_p models become unstable in the iterative process.

This factor must be chosen in order to obtain a trend of gravity variance reduction parallel to the seismic one, which is controlled by the damping factor of the seismic inversion. The correlation length λ introduces a forced correlation between the physical properties of two density prisms. If it equals to zero, the *a priori* information between two prisms is not correlated (this is the case in the seismic inversion), and when λ is different from 0 the prisms are correlated and the correlation increases with λ. The greater the correlation length λ is, the larger the structures and the anomaly wavelengths are.