Seismic data visualisation

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Abstract - The focal mechanism of an earthquake and fault plane solutions provide insight into the geology of an area. The objective of this paper is to give a means of better understanding fault movement when an earthquake occurs. In this paper we present an interactive 3D visualisation of possible fault plane solutions, which are usually represented as 2D "beach-ball" plots, with their respective block models. Additionally a 3D alleviation display of an area, with respective beach ball earthquake representations, provides a more in depth picture of seismological maps under the earth's surface. The program solution allows a better grasp of space, which is useful to students of seismology and anyone who wants to visualize fault movement of an earthquake.

Key words: interactive visualisation, fault plane, focal mechanism,

I. INTRODUCTION

Seismology is the scientific study of earthquakes. An earthquake is the result of a sudden release of energy in the Earth's crust in the form of seismic waves. The most common earthquakes are tectonic earthquakes, caused by rupture of geological faults. Faulting is relative movement of two geological blocks (walls), by creating a new fault or shifting along an existing fault plane [1].

The full process of an earthquakes hypocentre is very complicated and difficult to describe exactly. However, some of the properties observed on seismograms can be described by mathematical models of a point source with the conditions to observe phenomena far from the source and in the short time after the earthquake begins [2].

When the earth suddenly moves during an earthquake, energy is released and seismic waves radiate from the Earthquakes hypocentre in all directions [1]. The waves travel through the Earth's interior towards the surface. There are two types of waves: the faster longitudinal waves (P-waves) and slower transverse waves (S-waves). The waves are recorded by seismographs, and correspond to up and down movements on the seismogram [3].

II. FAULT MECHANISM

In the early 20th century, by observing the pattern of first motions (first arriving P waves), seismologists noticed that the first movement of a seismographs pen (recorded direction of the first shift of a geological block)
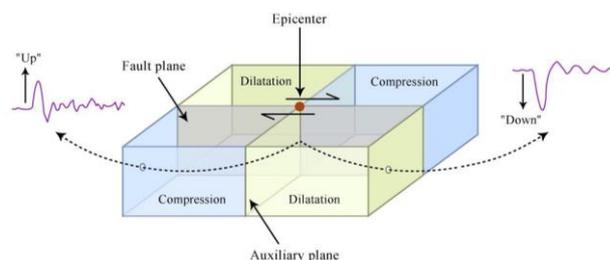

Figure 1. First motions observed from different directions[2].

depends on where the station is located relative to the epicentre [2].

The fault walls move in different directions which creates a different P wave polarity (seen in Fig. 1). If a block moves towards a seismological station, the seismograph will record the first shift as a compression with an up movement, but if a block moves away from the station, it is called dilatation and it will be recorded with a down movement. On a map, these areas can be divided by lines into four quadrants, each of which has a different polarity, but without further information there is no way to decide what type of a fault it is [3].

Seismologists examine the first motion of the P waves from local and remote stations to reconstruct the initial forces that triggered the event [1].

A. Fault types

There are three main fault types [2]:

- strike-slip, where the offset is predominately horizontal, parallel to the fault trace.

- dip-slip, offset is predominately vertical and/or perpendicular to the fault trace.

- oblique-slip, combining significant strike and dip slip.

An earthquake is described by the faults orientation and shift direction (seen in Fig. 2) [1]:

- Strike (φ) is the azimuth of a line created by the intersection of a fault plane and a horizontal surface, 0º to 360º, relative to North
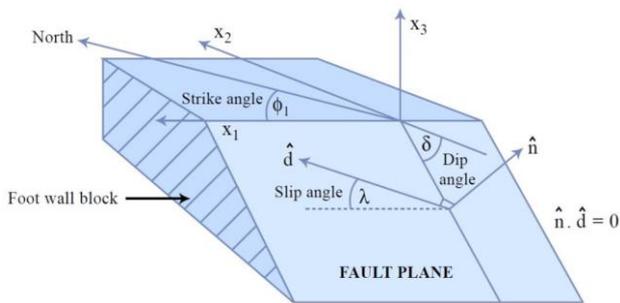
Figure 2. Fault geometry: fault orientation determined by the direction of the fault, dip angle and rake angle [3].

- Dip (δ) is the angle between the fault and a horizontal plane, 0º to 90º

- Rake (or slip, λ) is the direction a hanging wall block moves during rupture, as measured on the plane of the fault relative to fault strike, -180º to 180º (CCW)

The orientation is defined such that a fault dips to the right side. The hanging wall block is therefore always on the right, and the foot wall block on the left [1].

If the fault breaks the surface, the angles can be determined by geological methods, but in most cases, earthquakes do not break the surface and seismological data must be used to determine fault plane solutions [3].

B. Fault mechanism in practice

After an earthquake occurs, seismologists create graphics of focal mechanisms by mapping the P wave information on a focal sphere, informally referred to as a *beach ball*, to show the faulting motions that produced the earthquake. Focal mechanisms, also known as fault-plane solutions, are based on the direction of the first arriving P wave [1-4].

The orientations of the first P waves are gathered from a number of stations and plotted onto the focal sphere. If there are sufficient observations, two planes are drawn to divide the compressive from the tensional observations and these are the nodal planes (seen in Fig. 3). By convention the compressional quadrants are color-filled and the tensional (dilatation) left white [3,5].
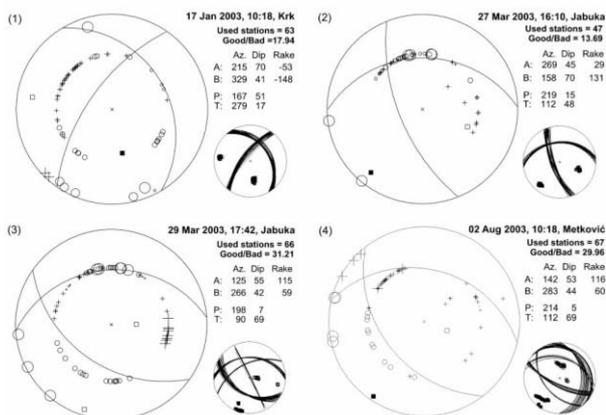

Figure 3. Focal mechanism examples for Croatian earthquakes that took place in Middle Dalmatia, the island of Krk and Jabuka [6]. The crosses represent compression and circles dilatation.

Figure 4. Example of ambiguity

The fault plane responsible for the earthquake will be parallel to one of the nodal planes, the other being called the auxiliary plane. Unfortunately it is not possible to determine solely from a focal mechanism which of the nodal planes is in fact the fault plane [3, 5].

A typical example can be seen in Fig. 4. A strike-slip fault with shift direction towards north (rake $\lambda = 0$º, strike $\varphi = 0$º) is indistinguishable from the strike-slip fault with shift direction towards west (rake $\lambda = 180$º, strike $\varphi = 90$º) [7].

To remove the ambiguity other geological or geophysical evidence is needed. There are a number of methods such as the terrain method (knowing the geology of the area will help identify the most likely fault geometry) or by comparing the two fault-plane orientations to the alignment of small earthquakes and aftershocks [7].

III. IMPLEMENTATION

Interpreting fault plane solutions can be difficult, especially because they are generally given as two-dimensional stereographic projections of the lower hemisphere of a focal mechanism sphere. In order to make it easier to understand and visualize, we present an interactive three-dimensional visualisation of faults and their matching beach balls.

The program solution offers the possibility of entering fault parameters (strike, dip and rake) with the option of seeing a matching beach ball as a three-dimensional sphere and the stereographic projection that is usually used on seismic maps. Furthermore a 3D relief display of Croatia, with respective beach ball earthquake representations of selected earthquakes provides a more in depth picture of seismological maps under the earth's surface.

To make our solution easily available for learning purposes, the technologies used were WebGL with the Three.js JavaScript library.

A. Fault visualisation

To simplify an earthquake process, geological blocks are displayed as cuboid bodies (seen in Fig. 5). A transparent plane represents the fault plane and a helper
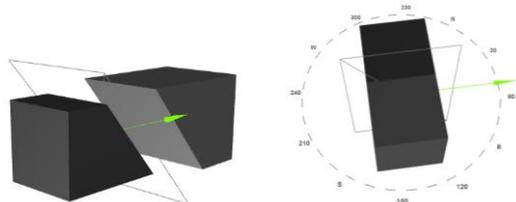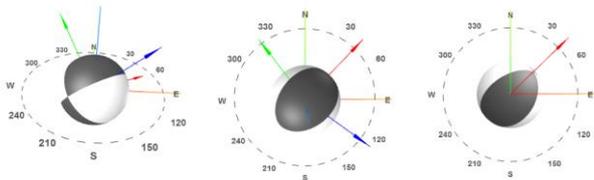

Figure 5. Fault visualisation

Figure 6. Beach balls with local and global axis

vector shows the direction of the hanging wall. Additionally, a compass points around the fault blocks helps to show the azimuth relative to north. The hanging wall shift is emphasized for the sake of demonstration.

B. Focal sphere visualisation

The focal sphere, informally referred to as a beach ball, is a sphere divided into four parts. The color fields describe a shift from the focus (compression), while white fields describe towards the focus (dilatation).

For better understanding, the beach ball is shown both as a 3D interactive sphere and as a generally used two-dimensional stereographic projection of the lower hemisphere.

C. Fault visualisation with the focal sphere

To better illustrate the focal mechanism solutions, we take as an example the earthquake that took place near the island Jabuka on 27th March 2003 (which focal mechanism solution can be seen in Fig.3) and show both of the possible solutions as a block model with the respective beach balls. The ambiguity between the two possible physical solutions obtained from seismic data and seen in Fig. 6 can now easily be seen from the presented block model and the corresponding focal spheres.

D. Relief map

One of the methods to remove the ambiguity is the terrain method, where knowing the geology of the area will help identify the most likely fault geometry. For this
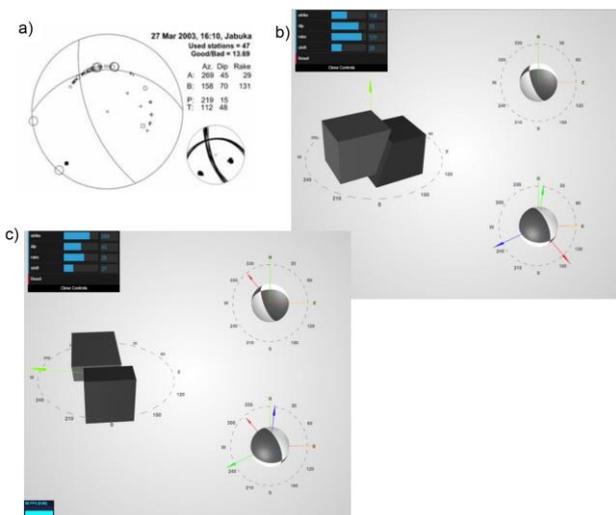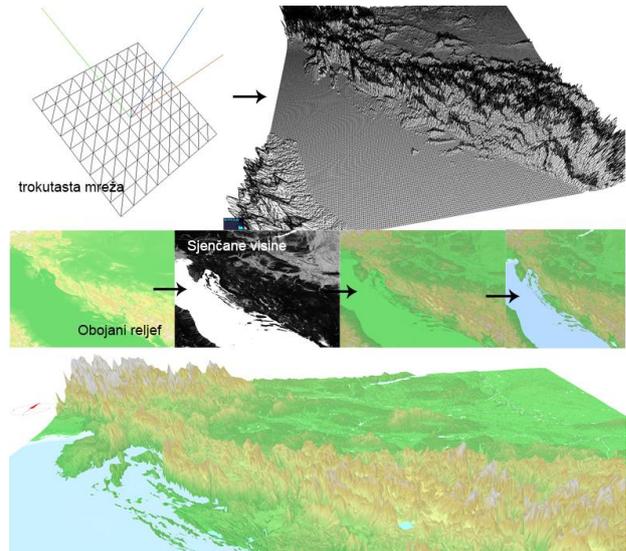

Figure 8. The process of creating the terrain map

purpose we made a map of Croatia on which we placed focal mechanism solutions of representative earthquakes from the Archives of the Department of Geophysics [8].

The height map and terrain texture were made based on data from OpenTopography [9-13] and Corine Land Cover dataset from European Environment Agency (EEA) [14]. The area covered is from 42 ° to 47 ° N and from 13 ° to 20 ° E. The process and final map can be seen in Fig. 8 [15-18]. The relief was accentuated for demonstration purposes. Selecting a beach ball shows information about the earthquake (date, magnitude, coordinates and depth), the block model and corresponding beach ball (seen in Fig. 9).
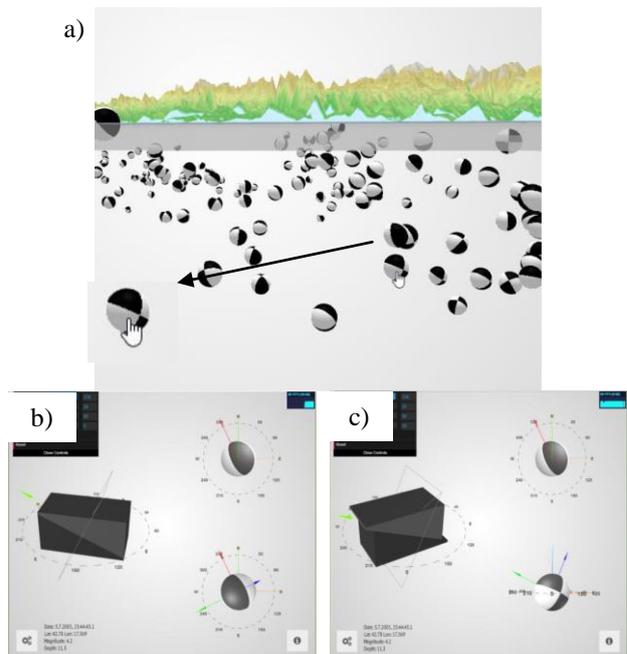

Figure 7. Visualized data from the earthquake that occurred near the island of Jabuka on 27th March 2003

Figure 9. a) Selecting a particular earthquake shows b) the focal mechanism of the earthquke, where one can change the view angle and visualise the shift of the fault plane in space. This example shows an eathquake that took place on 23rd March 2005 at 23h 44m, magnitude 4.2 (φ = 334º, σ = 24º and λ = 90º).
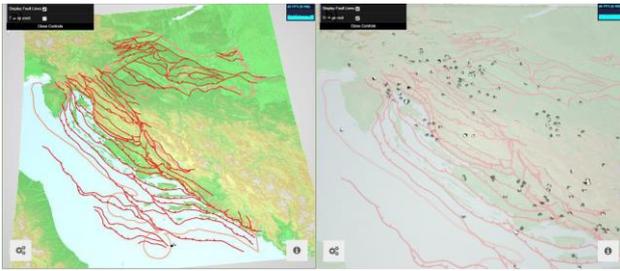
Figure 10. The map with the Geological map of Croatian faults (shown with full opacity and partly transparent so the beach balls can be seen from all angles)

Furthermore, we add a second texture showing the Geological map of Croatian faults (seen in Fig. 10) [19].

Fig. 11 shows how this allows for a better visualisation of fault plane solution spatial distribution.

E. User interface

The program was implemented using WebGL and Three.js JavaScript library as a website [20]. The menu is in the left bottom corner, where the user can change between the focal mechanism visualisation and catalogue of Croatian earthquakes in map view. It takes a little time for beach balls representing the earthquakes to load and apply needed transformations, as there are quite a number of them.

IV. CONLUSION

Focal mechanisms are determined based on earthquake analysis from a number of seismic stations. Its importance lies in the geological and seismological information that is gained about an earthquake's physical process. Fault plane solutions allow insight into the geological structure of an area.

The main objective of this paper was to give a means of better understanding fault movement by giving an interactive 3D visualisation of possible fault plane solutions (usually represented as 2D plots) with their respective block models. The program solution allows a better grasp of space, which is useful to students of seismology and anyone who wants to visualize fault
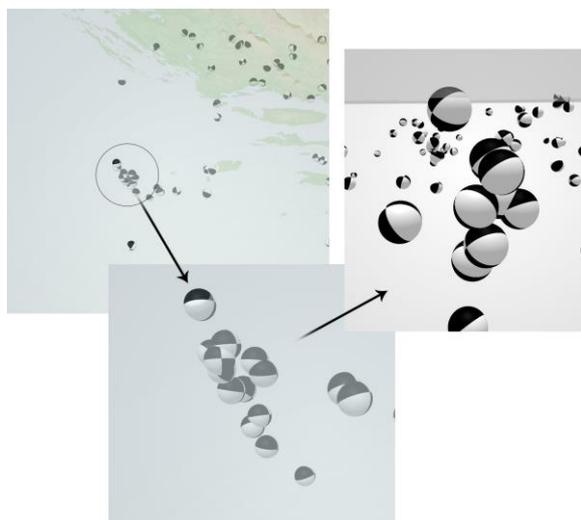

Figure 11. Different viewpoints of Jabuka epicenter area

movement of an earthquake.

Additionally a 3D relief display of Croatia with respective beach ball representations provides a more in depth picture of seismological maps under the earth's surface.

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