6. Conclusions and future works

6.1. Conclusions

In this Ph.D. Thesis we study the spontaneous fully dynamic problem for faults of different dimensionality and obeying to different constitutive laws.

The first part of the work is oriented to the presentation of the numerical methods, that have been implemented or proposed. Such a numerical algorithms, coded in `FORTRAN90`, make us able to solve the fundamental elastodynamic equation for different planar faults and adopting all the constitutive models proposed in the literature from 70s up to now. These codes represent an important tools in our research project, because of their versatility and their performances, as most of them are vectorized and parallelizables. We do not discuss all the details of those methods and we refer to our papers for a detailed analysis.

As no analytical solutions in closed form exists for the spontaneous fully dynamic problem, these codes are our instruments to found solutions and to study the physical processes described by friction laws. We were interested in studying the stages of the nucleation, of the dynamic propagation and stress release, as well as the arrest and healing phenomena.

In Chapter 2 we have shown that Dieterich laws (Dieterich, 1986; Ruina, 1980, 1983) are able to describe a dynamic rupture propagation in a 2 – D pure in – plane fault. In particular, we have shown that also in rate – and state – dependent friction laws framework it is possible to have a crack tip bifurcation ,in the sense that the main front is splitted in two sub – tips: one accelerate asymptotically up to the P – wave velocity. This represent a questioning point in the scientific community, because no clear evidences of such a bifurcation exist. Only laboratory experiments made on metal and plexiglas by Rosakis and coworkers (Rosakis et al., 1999) have shown that it is possible to have a rupture propagation at speed greater that S – wave velocity. Even if theoretical results by Burridge (1973) and Andrews (1976a, 1976b) clearly demonstrate the possibility and the condition under which bifurcation and super – shear ruptures take place, real – world events data are more contradictory and the propagation at v_P is still an open question.

In that Chapter we have also shown that Dieterich – Ruina laws can be regarded as an unifying constitutive formulation. Also rate – and state – friction laws implicitly contain a slip – weakening behaviour, but they can also model different physical process, like slip – hardening and fault restrengthening. We theoretically derived a scaling relations to associate constitutive parameters of the Dieterich law to those of slip – weakening model.

We demonstrate that both with the slip – weakening laws and rate – and state – dependent ones it is possible to model the rupture arrest. The simulations presented in Chapter 3 represent a generalization of the coupled asperity model proposed by Boatwright and Cocco (1996) and make us able to simulate real configuration in which the observed slip complexity is a natural consequence of the heterogeneous distribution of the frictional parameters. We model short slip duration, slip pulses (or the so – called self – healing) and we emphasize that all these phenomena are described by the friction laws.

In Chapter 4 we present the numerical method that we have written to simulate a system of multiple 3 – D non parallel planar faults obeying to different constitutive laws. Such a Finite Difference program, based on a numerical code by Joe Andrews, can be regarded as the state of the art of the numerical modelling of the dynamic fracture and waves propagation. We presented only results applying the slip – weakening model, in order to emphasize the differences between 2 – D and 3 – D models. It is clear that 3 – D ruptures are more realistic and allow for a more deep description of the rupture processes, like rake rotation during propagation, influence of the surrounding medium and interactions between free surface. We have shown that the mixture of two modes of propagation (pure in – plane and pure anti – plane) can influence the bifurcation process.

The second part of the Ph.D. Thesis is focused on the fault interactions and stress triggering. We used a simple spring – slider model, with only one degree of freedom, that, in spite of its simplicity, make us able to found some general aspects of triggering phenomenon. It has been shown that static, permanent stress perturbation are able to move the system form its old state and cause a triggered failure, while pure Gaussian (pulse like) stress perturbation are in general unable to anticipate a seismic event.

6.2. Future works

As the nowadays progresses in the Information Technology are fascinating and in a certain sense terrific, we believe that an important point of our future researches is to implement and improve news algorithms to solve the dynamic problem. We can compare different numerical schemes and do benchmarks with various fault boundary conditions, in the spirit of Bizzarri et al. (2001). But a numerical code is simply a tool and we aim to stress on more conceptual and less technical topics of future works.

The study about fault interaction and stress triggering that we did in

Belardinelli et al. (2003) it is only introductory, because it have emphasized the main aspect of the problem. The simple model used (the spring – block system) is only an idealization of a real fault. In the future we will use the 3 – D model described here to analyze in a more realistic way the interaction processes.

An important point of feature developing is represented by the problem of the constitutive formulation. As we have described in Chapter 1 the more general governing equations contain a large number of observables, that we do not consider in this Ph.D. Thesis. One of the most important is the normal stress, that in general can be varying during a rupture. As demonstrated by Day (1982), two different material in contact causes a normal stress variation, and such an effect may be also caused by fluid migration (due to frictional heating). We will check the effect of fluid pressurization, proposed by Andrews (2003) for a simple two levels friction laws, on a realistic 3 – D rupture obeying to various governing laws.

A final possible future work might be the complication of the fault geometry, like non planar fault (as proposed by Aochi et al., 2000), or admitting material interpenetration and crack opening, that is formally kown as 4 – D problem.