Quantization of large earthquakes driven by asperities strain concentration patterns

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ABSTRACT

The role of asperities in fault evolution has been received continuously increasing attention as critical areas where nucleation and cascade like failure may take place. They consist patches where the contact takes place across the fault rough surfaces, accumulating elastic strain during the interseismic period. More than one asperity rupture result to strong and large earthquakes, a phenomenon mostly characterizing large subduction earthquakes. Identification of the factors controlling single or multiple asperities failure and their spatiotemporal behavior is a key issue in seismic hazard assessment. It is the aim of the present work to explore the role of different spatial patters of asperities as well as their different strength characteristics by means of simulation experiments via cellular automata models. Initial results show that the earthquake distribution clearly depends on a) the fraction of strain that asperities may sustain in comparison to the corresponding value of the non–asperity sites, b) the relative distance between asperity patches and c) the total real contact area of asperities. There is a definite range of the aforementioned controlling parameters, which result to a non–typical earthquake magnitude distribution and where a clear departure from the classical power law–like Gutenberg – Richter relation is depicted. More specifically, for one (more than one well separated) asperity (–ies) with significant fraction of strain unlocking thresholds a non–typical earthquake size distribution emerges where for low magnitude earthquakes a power law still holds, but for higher earthquake sizes, a quantum like behavior emerges, i.e. there is one (more than one) certain earthquake sizes that are more probable to occur. This manifests a characteristic earthquake model, which although not adequately supported by observational data, is present in several applications of simulator models.

INTRODUCTION – THE MODEL

The present model is a modification of the classical OFC cellular automaton model accounting for the fact that the real contact area within fault is smaller than the geometrical due to the presence of asperities. The following modifications are introduced:

- Nodes that are in contact experience a specific maximal friction F^{c}_{th}
- Non – contact nodes experience an average static friction F^{nc}_{th} due to screening effect, e.g.

  F^{nc}_{th} = RCA * F^{c}_{th} , RCA: % contact area
- The arbitrary node n_{ij} slips if its stress is larger than F^{c}_{th} (F^{nc}_{th}) within real contact area (outside real contact area)
- The redistribution of forces to the neighboring sites is taking place as follows:

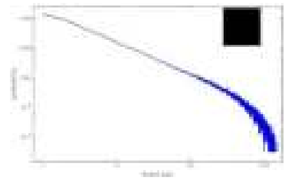
  $$f_{ij} \to 0 \quad f_{mm} \to a_{ij} f_{ij}$$

  where f_{mm} is the stress at each of the four nearest neighbors and

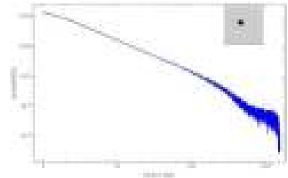
  $$a_{ij} = \begin{cases} a^{c} < 0.25 & \text{within real contact area} \\ a^{nc} \approx 0.25 & \text{anywhere else} \end{cases}$$

EFFECT OF STRAIN PATTERN

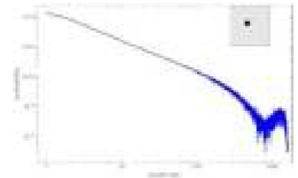
Uniform distribution of friction stress without asperities. System size L=40x40, a^{c} =0,2495 (within RCA), F^{c}_{th} : uniform within range 0-4



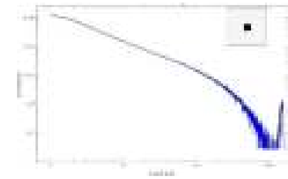
Introduction of square asperity with RCA = 3% and F^{c}_{th}= 20



Square asperity with RCA = 3% and F^{c}_{th}= 40. Other parameters as before.

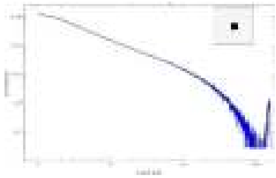


Square asperity with RCA = 3% and F^{c}_{th}= 100. Other parameters as before.

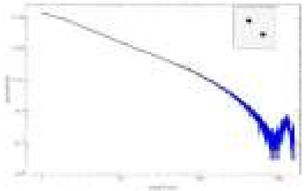


EFFECT OF ASPERITY SPATIAL PATTERN

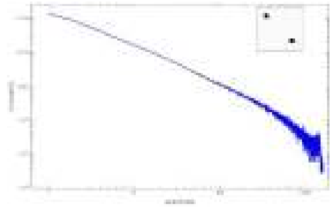
One square asperity with RCA = 3% and F^{c}_{th}= 100



Two square asperities in short distance with same RCA and F^{c}_{th} as before

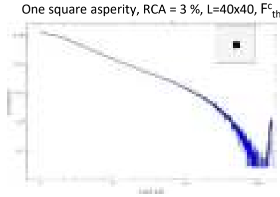


Two square asperities well separated with same RCA and F^{c}_{th} as before

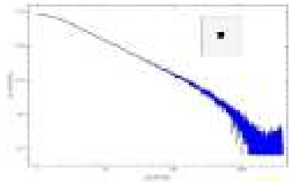


EFFECT OF SYSTEM SIZE AND REAL CONTACT AREA

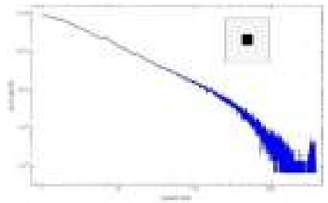
One square asperity, RCA = 3 %, L=40x40, F^{c}_{th}= 100



One square asperity, RCA = 3% and L=64x64



One square asperity, RCA = 6.25 % and L=64x64



DISCUSSION

In this work we investigated a modification at the classical OFC model by introducing asperities patterns which accumulate elastic strain during the interseismic period. The common hypothesis that more than one asperity rupture result to string and large earthquakes, has been addressed in the first set of simulation runs, studding the effect of asperities strain patterns. It can be seen that an indirect proof of the aforementioned hypothesis has been established: the presence of an asperity, even with a low real contact area, result in the emergence of a high probability of large events. More surprisingly, above a certain threshold of asperity friction stress (F^{c}_{th}~40) a quantization of large earthquakes emerges.

In the second set of simulation experiments, the emergence of large earthquake quantization under different asperities spatial pattern has been studied. It can be seen that when asperities patches are small and distant their effect vanishes in relation to one bigger asperity patch, both patterns having the same real contact aera.

Finally, the role of system size and real contact area has been studied in the third series of simulation experiments. Initially, keeping all the other parameters constant, the system size was increased. It can be seen that in this case quantization of large earthquake events vanishes again. In order to preserve quantization in large systems it is necessary to increase simultaneously the real contact area at asperities. Indeed this is the case of the last simulation figure when keeping all the other parameters constant, the increase of RCA from 3% to 6,25% had as a result the reemergence of quantization of large earthquakes.

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ACKNOWLEDGMENTS

This work was supported by the «Telemachus – Innovative Seismic Risk Management Operational System of the Ionian Islands» which is part of the Operational Program «Ionian Islands 2014-2020» and is co-financed by the European Regional Development Fund (ERDF) (National Strategic Reference Framework - NSRF 2014-20).