SPATIAL APPROACHES FOR ANALYZING HISTORICAL EARTHQUAKES ASSOCIATED WITH THE DEAD SEA TRANSFORM

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ABSTRACT

Historical reports, archaeoseismic evidence and plaeoseismic findings of pre-instrumental earthquakes occured along the Dead Sea Transform (DST) are available for the past 3000 years. Most of them were already collected and organized in various catalogs, reappraisals, and lists. Using spatial interrogation of old visual sources such as drawings, maps and photographs, earthquake damage localities were resolved thus enriching the existing knowledge base and contributing new spatial approaches. Examples are the damage detection and spread in Jerusalem and Tiberias after the 1927 and 1837 earthquakes, respectively. Then, a comprehensive and consistent compilation of the historical seismicity associated with the DST as an integral seismogenic unit was spatially and temporaly examined. The compilation resulted in 208 reliable historical and post-19th century instrumental earthquakes (from the mid-8th century BCE until 2015 CE), and 112 doubtful ones. Characterization of the temporal and spatial patterns of DST seismicity, classified into 4 geographical sub-zones, was implemented. Accordingy, it was detected that the occurrence of destructive earthquakes shifts south-to-north along the DST, in which an occurrence of a southern event is followed by consecutive northern destructive activity.

Keywords: Historical earthquakes, damage, Dead Sea Transform, Spatial and temporal analysis

1. INTRODUCTION

Numerous sources of historical earthquakes occured in the Levant, including the damage and effects they caused have been accumulated over the last 3,000 years. They include historical accounts, archaeoseismic remains and paleoseismc findings. Most of them, were already collected and organized in various catalouges, reappraisals, and lists [e.g., 1, 2-4]. In many cases, the damage description extracted form these sources can be used to conclude siesmic intensities [5] asisting in concluding earthquake charecteristics (e.g., location and magnitude) [6, 7]. Among the historcal sources, one can list numerus visual sources such as old drawings, maps, photographs and air-photos [8] which can be spatialy interogated for resolving earthquakes damage. The rapid development of imagery software and GIScience (Geographic Information Science) enable us a suitable framework for developing new methodologies targeted at tracking past earthquake damage [e.g., 9, 10]. Furthermore, they also foster the ability to examine and detect spatial and temporal patterns, clusters and repating activity associated with a seismogenic unit [11]. Accordingly, the objectives of the study are: (1) Saptial interrrogation of visual sources to resolve earthquake damage; and (2) Spatial and temporal examination of historical earthquakes to increase our understanding of the Levantine seismic behavior.

2. METHOD AND DATA

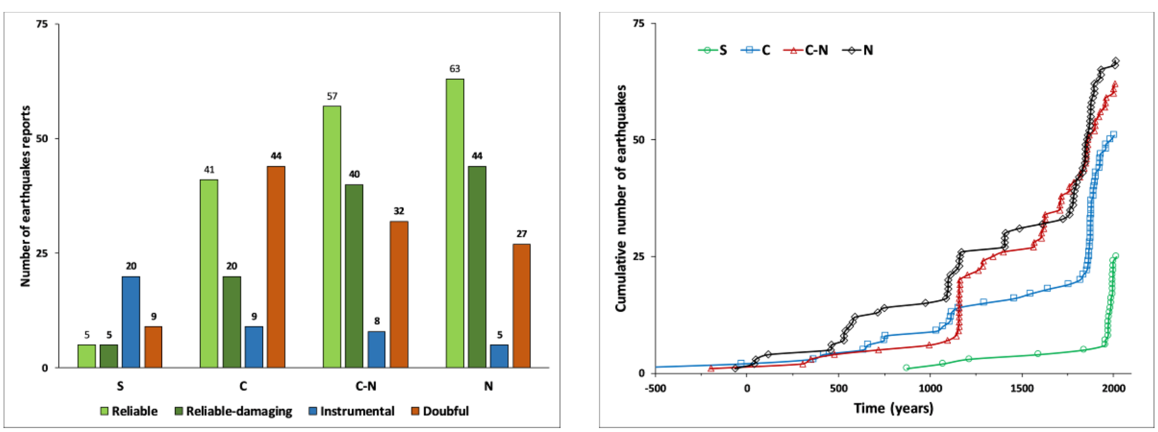
For the task of resolving earthqauke damage, existing archives of various visual sources were exploited. The suitable visual sources were compiled with textual reports, archeological data and field surveys. For the 1927 earthquake [12] hitting Jerusalem, the spread of metal iron anchors using old photographs was inspected. These were installed on damaged walls after the earthquake to prevent their further deterioration and thus proxy of damaged structures (Figure 1a). Some of the photographs, the anchors appear so small and well embedded within their surroundings that without considerable magnification accompanied by detailed field surveys their detection was almost impossible. For the 1837 earthquake [13] in Tiberias, nearly 50 drawings, maps and photographs were examined and compiled with written accounts (Figure 1b). Precise digitations of the shape of Tiberias's main features were made in a GIS-based framework and three-dimensional models prior and after the 1837 earthquake were established. The models allow for 360˚ areal and vertical examination enabling full evaluation of the damage. The rest of the earthquake entries and the resulted damage was collected and compiled using modern and early catalogues, reappraisals and focused investigations of specific events to establish a complete and reliable database for the spatial and temporal inspection.

(**a**) (**b**)

Figure 1. Data used for resolving damage: (**a**) Iron anchor on collapsing walls in Jerusalem after the 1927 earthquake (photograph: M.Z); (**b**) an old drawing of Bernatz (1839) portraying the damage to Tiberias walls after the 1837 earthquake [14]

3. RESULTS AND DISCUSSION

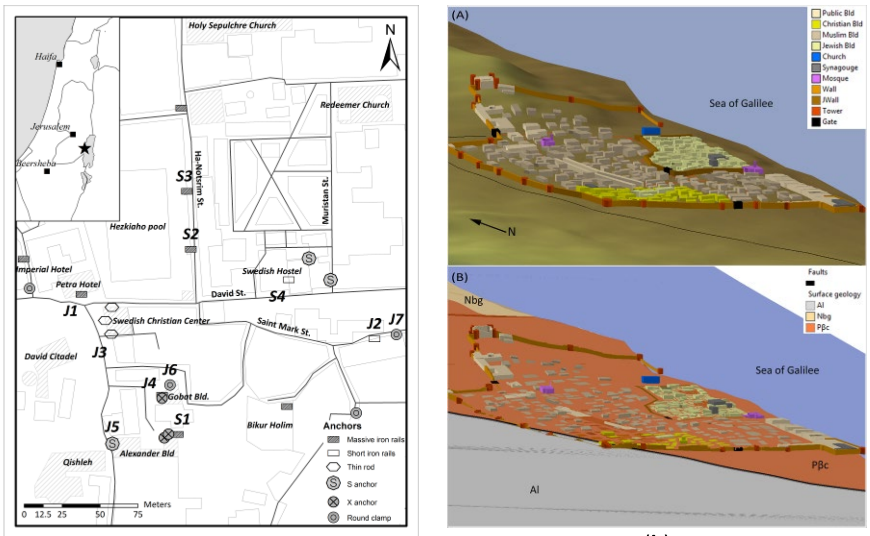
Three lists of were compiled (Figures 2a, 2b): (1) 208 reliable earthquakes associated with DST activity (excluding foreshocks and aftershocks) together with the 42 M ≥ 5 instrumental earthquakes (between 1903 and 2015); (2) 112 doubtful events; that is, duplications, conflicting interpretations of the historical records, fake events or questionable earthquakes that to date remain unauthenticated; (3) 71 reliable events that affected or damaged regions close to the DST but their most reported damage zone is far away from any DST zone. In accordance with the damage spread, each of the earthquakes were associated with a sub geographic zone of the DST (South, Center, Center-north and North) (Figure 4).



(**a**) (**b**)

Figure 2. (**a**) Classification of earthquakes (excluding foreshocks and aftershocks) into DST zones (S, C, C-N, and N): (1) reliable earthquakes; (2) reliable damaging earthquakes; (3) instrumental earthquakes (1903–2015 C.E.); and (4) doubtful earthquakes; (**b**) Cumulative reports of reliable earthquakes occurred between 198 B.C.E. and 2015 C.E. classified into the DST zones.

The damage distribution in Jerusalem and in Tiberias after the 1927 and 1837 earthquskes is presented in Figures 3a and 3b, respectively. Using georeferenced visual sources and spatial analysis of the details they contain it was possible to portary the damage in high resulution. In Jerusalem, in the Christiam quarter alone, more than 10 new damage localities were detected while in Tiberias, a complete damage reconstruction using GIS models was achived.



(a) (b)

Figure 3. High resolution damage spread: (**a**) 1927, Jerusalem; (**b**) 1837, Tiberias.

Classifying the DST into four zones indicates 5, 41, 57, and 63 earthquakes (excluding foreshocks and aftershocks) in the S, C, C-N, and N zones (Figure 4). With Chi-square tests, it was found that a single earthquake sequence, that is followed by chronological successive earthquake in a different zone, appears 88%, 83%, 67%, and 59% of the total sequences of the S, C, C-N, and N zones, respectively.

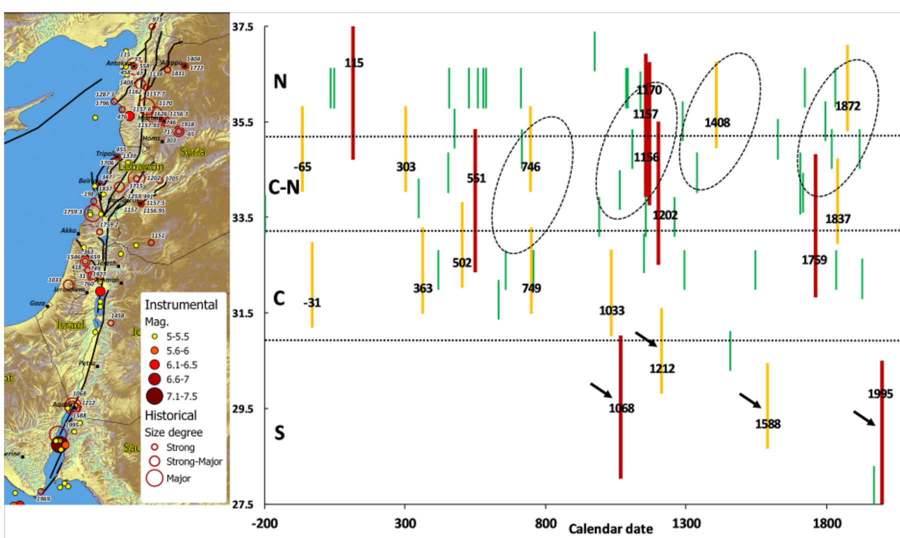


Figure 4. (**a**) Inferred most reported damage zone (MRDZ) locations of historical earthquakes. The epicenter of instrumental earthquakes (post-19th century) is positioned together with adjacent magnitude. (**b**) Spatial and temporal distribution of earthquakes during the last three millennia. Strong, Strong-major, and Major earthquakes are scaled in length and noted by green, orange, and red vertical lines, respectively, with center points aligned with map location to the left.

Furthermore, in S and C zones there are no sequences greater than two successive earthquakes. Additionally, 41%, 36%, 14%, and 13% of the successive earthquakes at the same zone occur in the N, C-N, C, and S zones, respectively. That is, the northern seismic activity in the C-N and N zones is more clustered than in the S and C zones.

4. CONCLUSIONS

Two examples of earthquake damage analysis were presented. Considering the lack of data associated with pre-instrumental earthquakes, further interrogation of visual sources should be fosterd to increase our knowledge base.

The observed south–north shifts of DST activity implies of a postulated alternation pattern of strong seismicity. For further investigation, the spread of the damage of each earthquake should be evaluated accurately and then tied to a potential triggering tectonic segment.

The study conducted and the database established may serve as a base for future studies of the DST as a complete tectonic unit. Further interdisciplinary efforts should be made particularly in resolving the full scope and severity of the resulted damage, which may assist substantially in refining the presented results.

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