HISTORICAL SEISMOLOGIST

Earthquake Damage and Repair: New Evidence from Jerusalem on the 1927 Jericho Earthquake

by Motti Zohar, Rehav Rubin, and Amos Salamon

Online Material: Four additional photos.

INTRODUCTION

On 11 July 1927 at 15:04, an earthquake struck Mandatory Palestine and its close surroundings, resulting in considerable casualties and damage (Avni, 1999). Recent studies estimated the epicenter at the north of the Dead Sea (Shapira *et al.*, 1993; Zohar and Marco, 2012) and a magnitude of M_L 6.25 (Avni, 1999). Jerusalem, located nearly 30 km west of the epicenter, suffered greatly in the earthquake. Many of its structures were damaged, leaving several people killed, many injured, and a few hundreds homeless. The governing British Mandate commissioner responded quickly and almost immediately instructed the Public Works Department to initiate field surveys and to recommend necessary repairs (Avni, 1999). One of the strategies implemented for repairs was the use of a metal apparatus, referred to as iron anchor, to stabilize damaged structures and walls (Willis, 1927; Michaeli, 1928).

During a recent field survey initiated within the area close to the Jaffa Gate in the Old City of Jerusalem, we have identified many iron anchors (Fig. 1). Varying in shape, size, and color, they appear mostly at higher sections of the outer walls of pre-twentieth century structures. In general, a pair of anchors is installed at two opposite sides of the weak structure, which are screwed into an iron rod to connect them together. This technique effectively ties the building together and consequently prevents its further deterioration (Fig. 2). We map these anchors and their geographic locations, characterize their host structures, and classify them into six types (Fig. 3).

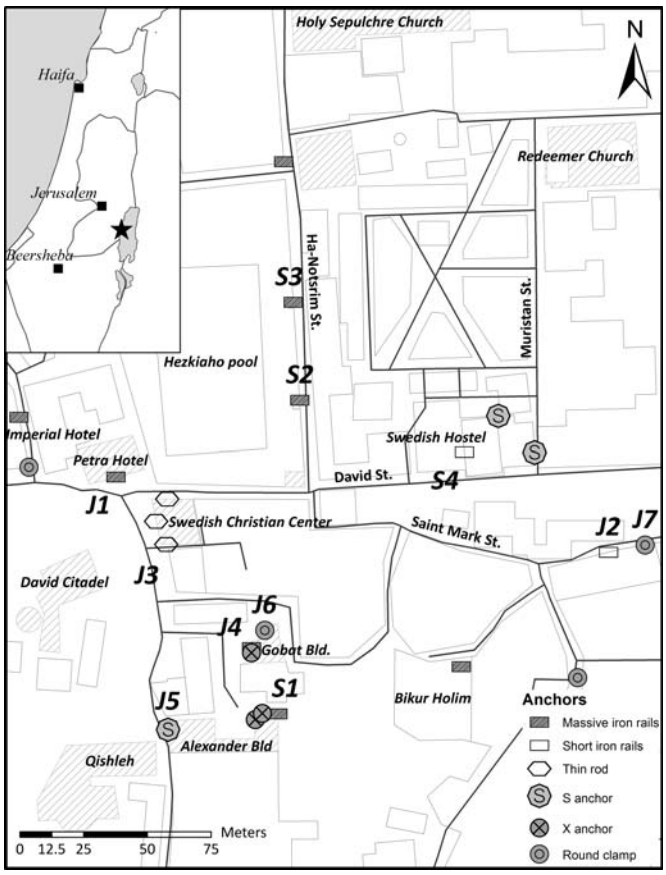
At first glance, the linkage between the anchors and the 1927 earthquake is clear. However, not all the anchors are associated with the seismic event; some were installed before (Michaeli, 1928) or long after it merely for the purpose of preventing continuous deterioration of weak structures. Unfortunately, we can hardly use written historical sources because most of them neither mention the use of anchors nor their exact placements of installation. Therefore, we must use other, unexploited sources to detect and to map the various anchors and single out those that were in fact used for repairing the damage due to the earthquake.

Although available for only a period of less than 200 years, old photographs constitute one of the most detailed sources available and have been used in numerous historical and geographical studies (e.g., Ben-Arieh, 1997; Rose, 1997, 2000, 2001; Borchert, 1981; Rubin, 1999; Karniel and Enzel, 2006; Levin *et al.*, 2010; Shay, 2011). Like written sources, old photographs must be investigated carefully for inaccuracies and incompleteness (Frosh, 2003). Fortunately, once they have been verified, old photographs supply us with contemporaneous detailed views and expand our ability enormously to examine past sites and scenes (Loitzus, 2000). Accordingly, we examined old photographs of Jerusalem taken a short time before and a short time after the earthquake to trace the possible earthquake–anchor linkage and identify those anchors that were installed only after the event. Similar comparisons aimed at analyzing earthquake scenarios were previously carried out using drawings (e.g., Ambraseys and Karcz, 1992) and photographs (e.g., Kelsey, 2007; Hinzen, 2013).

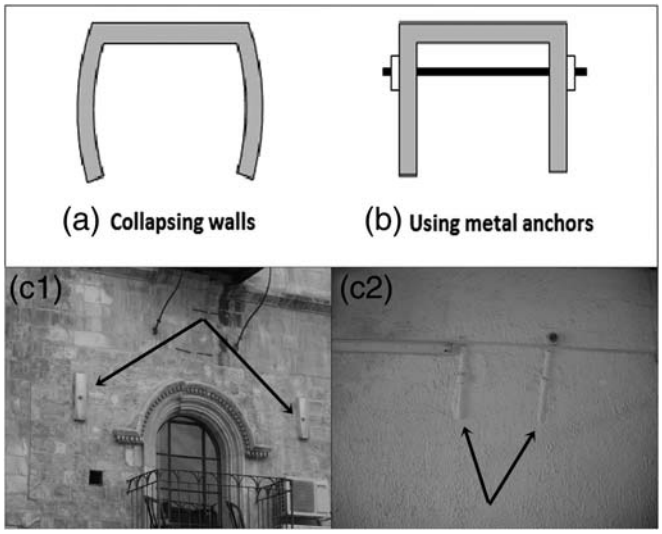
Being sacred to the three monotheistic religions and also constituting the political and economic center of this part of the Middle East in the late nineteenth and beginning of the twentieth centuries (Ben-Arieh, 1979; Biger, 1989), Jerusalem has attracted much public attention. Almost every photographer and visiting delegation devoted a substantial part of their journeys in the region to photographing the city (Perez, 1988). Many major festivals, religious events, demonstrations, and political clashes have occurred in Jerusalem, and in most cases were well documented (Schiller, 1980; Nassar, 1997). During and after World War I, views of the city were also taken from the air by German, British, and Australian aircraft (Gavish, 1978, 1989). All these activities contributed a large number of photographs that we could use for our purpose.

In this paper, we present 11 examples of views of Jerusalem around the time of the 1927 earthquake: 7 are shown within this paper (labeled J1–J7) and Ⓔ 4 are available in the electronic supplement to this paper (labeled S1–S4). Each example includes before, after, and current photographs of the inspected locality. In cases when the relevant details of a given photograph are difficult to discern, arrows point to the relevant features. These examples suggest a new methodology to portray in high resolution the varieties of damage in Jerusalem after the 1927 Jericho earthquake and consequently improve our ability to analyze possible damage that might take place in future seismic events.

doi: 10.1785/0220140009



▲ **Figure 1.** The research area and the locations of iron anchors with the anchors classified into six types. Sites labeled J1–J7 show the locations of the inspected buildings presented in this paper, and Ⓔ S1–S4 show the locations of those in the electronic supplement. Buildings denoted with diagonal hatching are reported to have been damaged in the existing historical sources. The epicenter of the 1927 Jericho earthquake (marked with black star) is depicted in the overview map at the upper-left corner.



▲ **Figure 2.** Iron anchor usage: (a) walls collapsing toward the outer side of the building; (b) wall strengthened after the installation of supporting anchors (a and b are adapted from: http://upload.wikimedia.org/wikipedia/he/c/c5/0gen_meticha.gif; last accessed April 2014); (c1) iron rail anchors on the front wall of the Petra Hotel (Photograph: R. Rubin, 2010). The outer apparatus is screwed on the wall to tighten the grasp of the anchor and thus press the wall inward; (c2) the inner pairs of the rails shown in c1 inside the hotel.

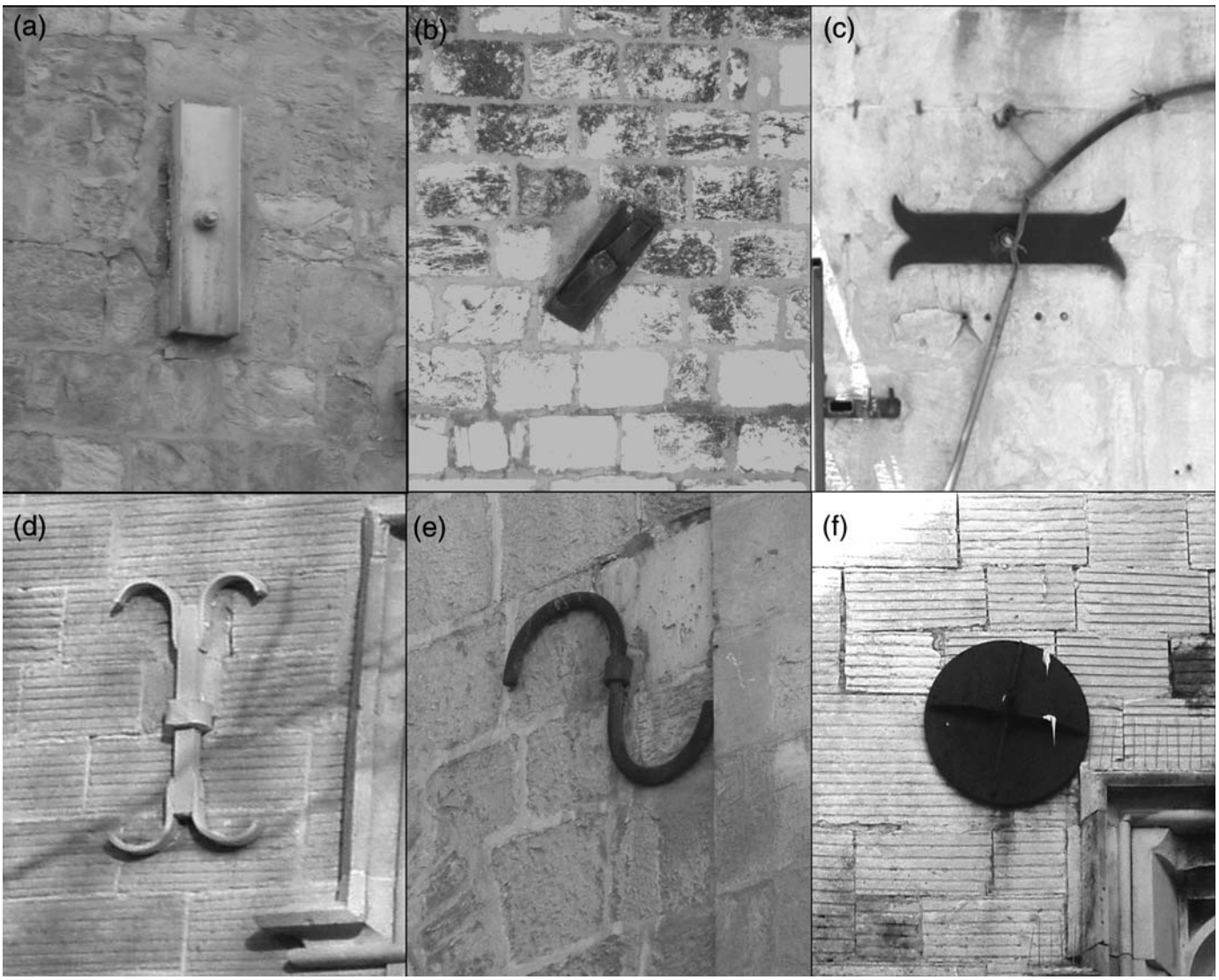
EXAMPLES FROM THE JAFFA GATE AREA

In the examples presented here, we detect the appearance of anchors installed in structures from old photographs. We verify which anchors were installed after the seismic event and which anchors allow us to draw conclusions about damage to the host structure. Occasionally, the desired anchor is hard to detect in a photograph because the photograph was out of focus or because the photograph was taken at a large distance from the structure (e.g., air photos). In such cases, we use the advanced imagery software ArcGIS Desktop to enhance the image resolution in order to detect anchors in these cases.

Type 1: Massive Iron Rails (Fig. 3a)

Facing south, the façade of the Petra Hotel (Fig. 1, locality J1) contains 12 massive iron rails located on the second and third floors (Fig. 4). These rails are made of massive steel, pressed inward into the wall by a single hexagonal screw with both sides of the rails covered by poor raw cement. Noticeable cracks occur on the second floor of the building, in particular above the western window. This impressive building was constructed during the 1840s by Joseph Amzalaq, a Jewish merchant from Gibraltar, but was sold later to the Greek Orthodox Patriarch (Kark and Glass, 1993). At the beginning of the twentieth century, it housed the Central Hotel, also known as the Amdursky Hotel (Zuta and Suckenic, 1920). After the earthquake, local newspapers reported that the building was damaged during the seismic event (Anonymous, 1927b,e). A photograph of the structure dated 11 December 1917 and documenting a proclamation by General Allenby contains neither installed rails nor observable cracks. On the other hand, in a photo dated between 1934 and 1939, rails above the balconies at the second and third floors are seen in the exact positions they are in today. The crack above the western window on the second floor can also be observed clearly in the 1934–1939 photos (Fig. 4).

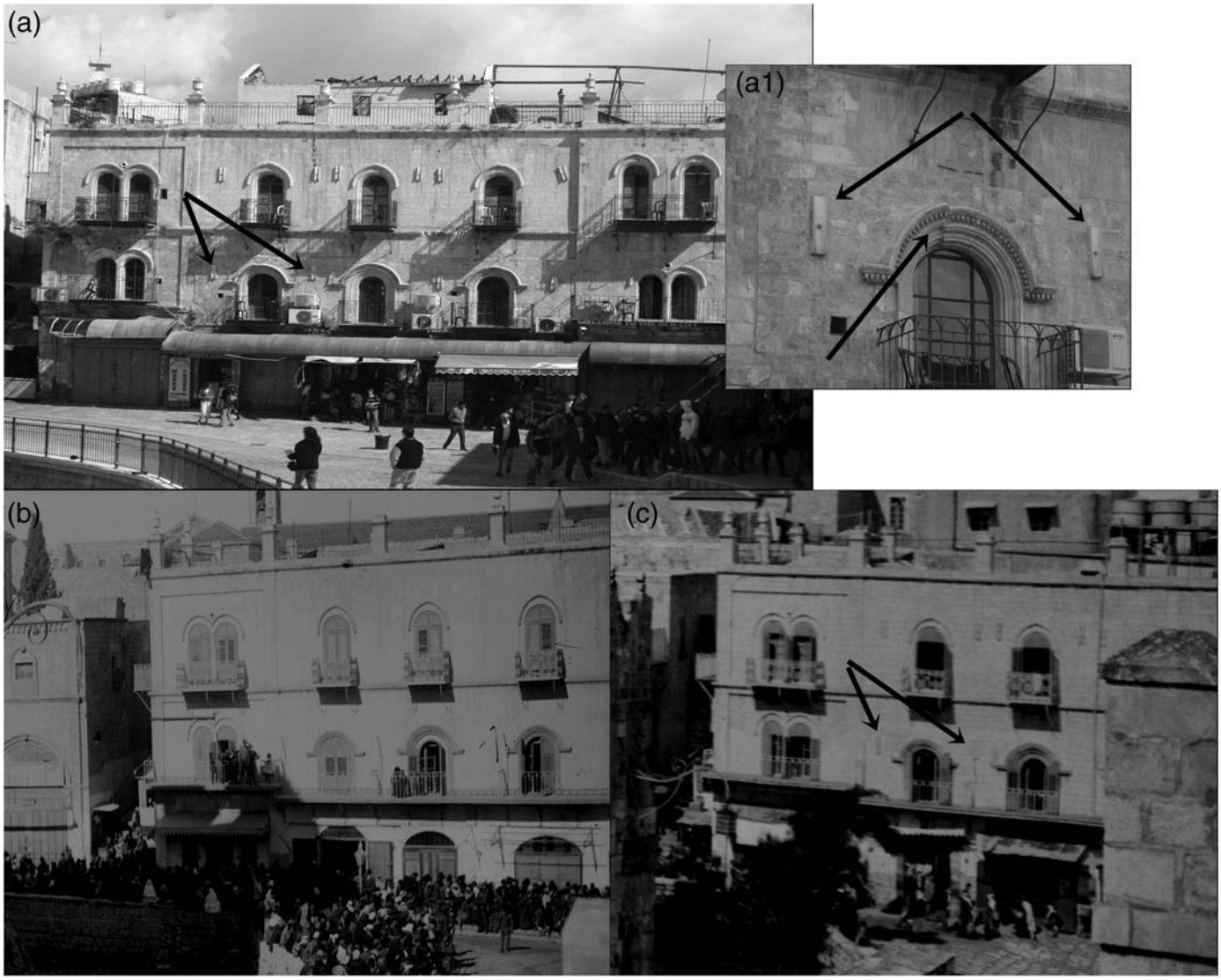
About 100 m south of the Petra Hotel, the complex of the English Christ Church stands with four buildings surrounding the main Church. The Alexander building is one of the surrounding structures, named after Bishop Alexander. It was built at the beginning of the twentieth century and constituted a vestry and a hostel (Sapir, 1987). In 1927, the eastern walls of the hostel were badly damaged, as documented in the records of a missionary journal (Anonymous, 1927a). Looking at the eastern wall of the building that faces the backyard of Christ Church, a pair of massive iron rails can be seen in a photo from their journal (Ⓔ Fig. S1). These two massive iron rails can be clearly detected in photographs dated later than 1927. Their



▲ **Figure 3.** Iron anchors and clamps observed in the research area: (a) massive iron rails, Petra Hotel; (b) short iron rails, Saint Mark Street; (c) thin rod, Swedish Christian Study Center; (d) X anchor, Gobat building, Christ Church; (e) S anchor, Alexander building, Christ Church; and (f) round clamp, Gobat building, Christ Church.

resemblance to those of the Petra Hotel implies that they might have been installed at the same time, probably by the same builders.

Two clusters of massive iron rails are found on buildings on the Patriarch Street, which begins at David Street, leads north and thus borders on the west with the Hezekiah Pool and on the east with the Church of the Holy Sepulchre. The first cluster, near the corner of Patriarch and Avtimus Streets, contains two massive iron rails (Fig. 1, locality S2). In a panoramic photograph by Bruno Hentchel from 1898, no anchors can be detected, whereas an air photo from 1931 clearly displays these two apparatus (Ⓔ Fig. S2). This is also concluded from an image of this building from its western side, which face the Hezekiah Pool. This view, photographed at an angle from the Petra Hotel roof, reveals the opposite tie of one of the rails. Both photographs contain views of the dome of the Catholicon, but only in one photo is the dome surrounded by scaffolding (Ⓔ Figs. S2, B2). The presence of these scaffolds implies that the photograph was taken after the earthquake; because the dome was badly damaged by the earthquake shaking, engineers recommended its complete removal and reconstruction (Freeman, 1947). Thus, every photograph in which these scaffolds appear can be surely dated later than the earthquake. A similar identification of the timing of installation is carried out for the cluster of three rusted massive rails located in the upper part of a building at 74 Patriarch Street (Fig. 1, locality S3). In a photograph from 1898, the rails are absent, whereas they are evident in an air photo from 1931 (Ⓔ Fig. S3) and can still be seen today. Two photographs of the building, taken from the west from the Matson collection classified previously as prior to and after the earthquake, date the time period of the rail installation to around the time of the



▲ **Figure 4.** Petra (Amdursky) Hotel: (a) present-day façade: 12 white massive iron rails identified on the second and third floors. A noticeable crack is seen above the window on the second floor (see arrows in magnified image). (b) December 1917, during the proclamation of General Allenby (reprinted from American Colony Photograph Department, Allenby's proclamation being read, Jerusalem; G. Eric and Edith Matson Photograph Collection, Library of Congress, Prints & Photographs Division, 1917, LC-DIG-matpc-08011). The front wall of the hotel does not exhibit any apparatus or cracks. (c) After 1934 (reprinted from American Colony Photograph Department, *The Towers of David & Hippicus*, Jerusalem; G. Eric and Edith Matson Photograph Collection, Library of Congress, Prints & Photographs Division, 1934-1939b LC-DIG-matpc-00448). The iron rails are clearly observed.

earthquake. There are several reports of damage in the area of this building after the earthquake: the Church of the Holy Sepulchre was badly damaged (Braver, 1928; Willis, 1928; Freeman, 1947), and the newspapers *Haaretz*, *Davar*, and *The Times* also report few damaged buildings in Suq al-Batraq, that is, the Patriarch's Street (Anonymous, 1927d,e,f). Thus, the building also may have been damaged in the seismic event.

Type 2: Short Iron Rails (Fig. 3b)

Over the southern wall of a building located at the corner of Saint Mark and Jewish streets, a cluster of four short iron rails surrounds a replacement of the wall's building stones (Fig. 1, locality J2), implying that part of the wall had collapsed and new stones were inserted to fill the gap. No record of damage in this area due to the earthquake was found in the written sources. However, inspection of two old photographs, both taken from the vicinity of the Church of the Redeemer, shows that the short rails appeared in this wall only in the later photograph dated between 1934 and 1939, whereas they are not found in the first photo dated from 1898 (Fig. 5).

A cluster of four short iron rails is located on the western wall of the third floor of the Swedish Hostel (Fig. 1, locality S4). Differences in shape, structure, and color of building stones at the second and third floors imply either that the third

▲ **Figure 5.** The corner of Saint James and HaYehudim Streets: (a) current status (April 2011): both short rails and round clamps (see arrows) over the wall are visible. In addition, cracks are apparent in the same wall (marked by an arrow). (b) From the Church of the Redeemer, 1898, neither anchors nor cracks are visible (reprinted with permission from B. Hentschel, Panoramic view, Church of the Redeemer, Jerusalem, Leipzig: Yeri Rimon Collection, 1898 B. VIII). (c) Dated between 1934 and 1939 (reprinted from American Colony Photograph Department, Old City, Jerusalem, Jerusalem: G. Eric and Edith Matson photograph collection, Library of Congress, Prints & Photographs Division, 1934–1939 LC-DIG-MATPC-17817). Note that the round clamps do not appear.

floor was built as a supplement after the initial construction or that old stones in the original structure were replaced by new ones, possibly after significant damage to the wall (Ⓔ Fig. S4). This latter possibility is supported by the existence of the four short rails. There are no written sources indicating damage to this building. However, there is evidence implying damage to the building on nearby David Street (Avni, 1999). A photograph dated to the beginning of the twentieth century reveals no anchors at the Swedish Hostel. However, in a photograph from 1937 short rails do appear, and these apparently were installed after the earthquake to stabilize damaged walls. An attempt to identify these details from an air photo was unsuccessful due to the low resolution of the image.

Type 3: Thin Rods (Fig. 3c)

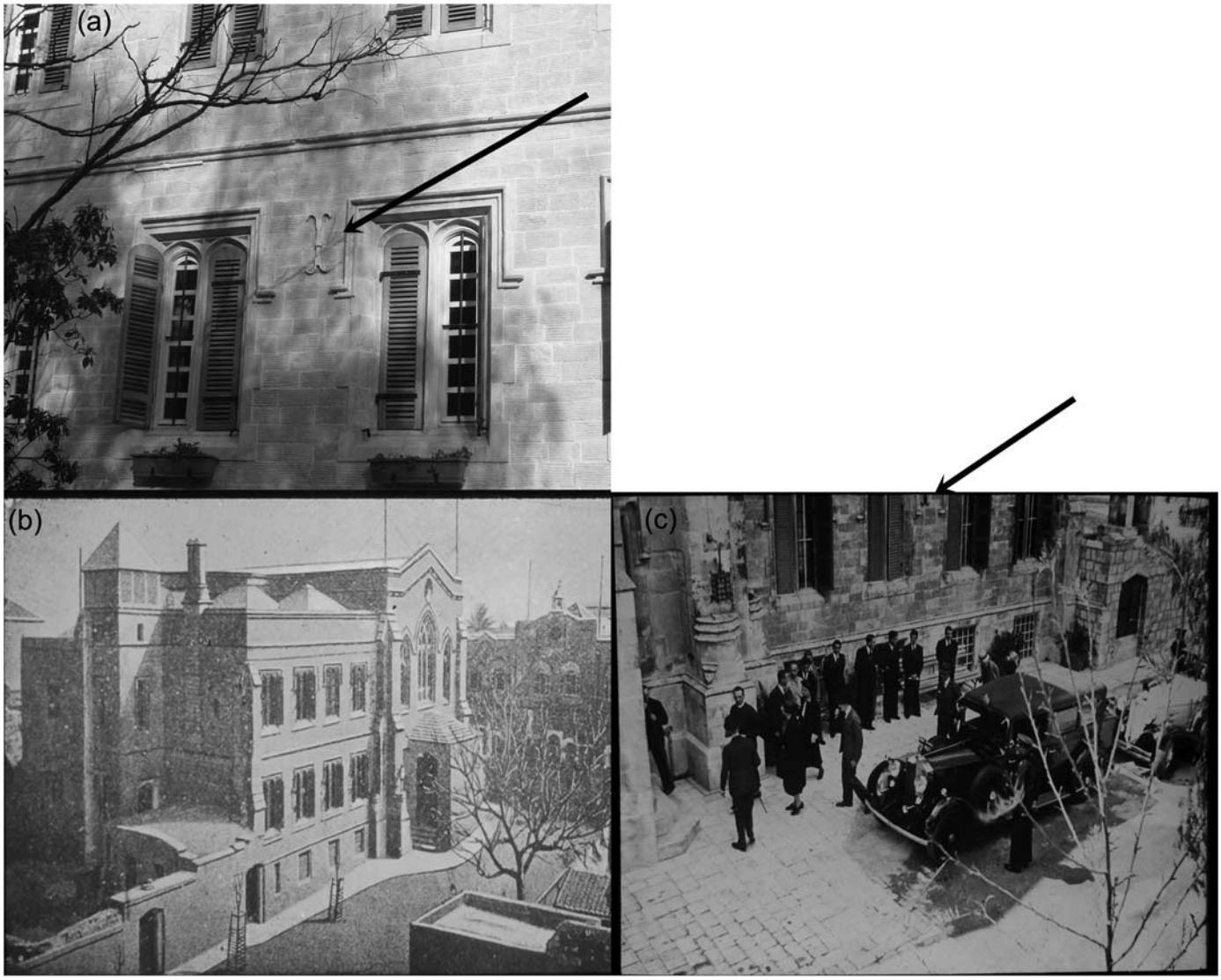
Other than the eastern wall, thin rod anchors are installed in each side of a nineteenth century structure (Fig. 1, locality J3) located next to the Petra Hotel. Unlike the Petra Hotel, these rods are flat pieces of iron, nearly two centimeters thick and differ from each other only in their length. At close range, one can identify one, five, and two thin rods on the northern, western (front of the building, facing the David Citadel), and southern walls, respectively. In the past, the building housed the American Consulate, which was established in 1844. Toward the end of the nineteenth century, the consulate moved outside of the Old City and the building was then occupied by the Thomas Cook Agency (Ben-Arieh, 1977). After the

▲ **Figure 6.** Swedish Christian Study Center: (a) two thin rods on the southern wall (April 2011); (b) the entrance of General Allenby in 1917 (reprinted from American Colony Photograph Department, arrival of Allenby to read a proclamation at the Tower of David, Jerusalem; G. Eric and Edith Matson Photograph Collection, Library Of Congress, Prints & Photographs Division, 1917 LC-DIG-MATPC-08013), no rods on the southern wall; (c) 1936 (reprinted with permission from Z. Oron, Jaffa Gate Area, Jerusalem, Jerusalem: Zionist Archive, 1936 PHO \1361014): two rods on the southern wall (marked by arrows).

earthquake, the building was reported to be partially damaged (Anonymous, 1927a). Available old photographs show only the southern wall clearly. No iron rods are seen in a 1917 photo, whereas they are clearly seen in a photograph taken in 1936. Therefore, they were installed between 1917 and 1936, probably after 1927 (Fig. 6). Unfortunately, the angle at which two photographs were taken does not enable close examination of the western and northern walls. Even so, there is a high probability that the rods were installed in each of the three walls at the same time.

Types 4 and 5: X-Shaped (Fig. 3d) and S-Shaped (Fig. 3e) Anchors

X- and S-shaped anchors are located on the Gobat and Alexander buildings of the Christ Church complex (Fig. 1, localities J4 and J5), respectively. The Jewish Missionary Intelligence from September 1927 reports that the old parsonage (identified as the Gobat building) and the eastern walls of the hostel (the Alexander building) were damaged. Additional news published in the *Davar* newspaper claimed serious damage to the buildings in front of the David Citadel (Anonymous, 1927a,c). Both buildings were built only after the establishment of the church. The Gobat building was completed in the middle of the nineteenth century and constituted the first residence of the British consul James Finn, whereas the Alexander building was built at the beginning of the twentieth century and constituted a vestry and a hostel (Ben-Arieh, 1977). In Figure 7, dated to the beginning of the twentieth century, the X-shaped anchor does not appear on the Gobat building. However, a photograph of the arrival of the High Commis-



▲ **Figure 7.** X-shaped anchor on the Gobat building, Christ Church: (a) April 2011; (b) the building at the beginning of the twentieth century (reprinted with permission from Anonymous, Christ Church Jerusalem; Conrad Schick Library, early twentieth century); (c) 1931, the reception of the high commissioner (reprinted with permission from Anonymous, the arrival of his royal highness the high commissioner to Jerusalem, 1930; Conrad Schick library, Jerusalem, 1931). Note the X-shaped anchor (marked by an arrow).

sioner at Christ Church taken in 1931 reveals a black X-shaped anchor. A similar phenomenon is observed on the Alexander building. The S-shaped anchors appear on the western wall in an air photo from 1931, whereas beforehand there were no signs of them (Fig. 8).

Type 6: Round Clamps (Fig. 3f)

These relatively well-decorated round clamps were detected in two localities within our research area. Next to the short iron rails at Saint Mark Street, three round clamps are also seen (Fig. 1, locality J6). Theoretically, the fact that both anchor types surround the same fissure might imply they were installed together, but scrutiny of the photographs rejects this and confirms that the round clamps were installed a few decades after the event (Fig. 5). Another pair of round clamps is installed at the top of the bell tower in the Christ Church complex (Fig. 1, locality J7). The eastern clamp facing the David Citadel is situated higher than the church's roof (Fig. 9), and thus it could be spotted from outside the Church complex. In a photograph dated approximately to 1945, the top of the bell tower is exposed, but no clamps can be detected. Consequently, we conclude the clamps were not installed after the earthquake, but at a much later time. Indeed, such clamps are found in many post-1967 renovated houses in the Jewish Quarter (Kroyanker, 1993).

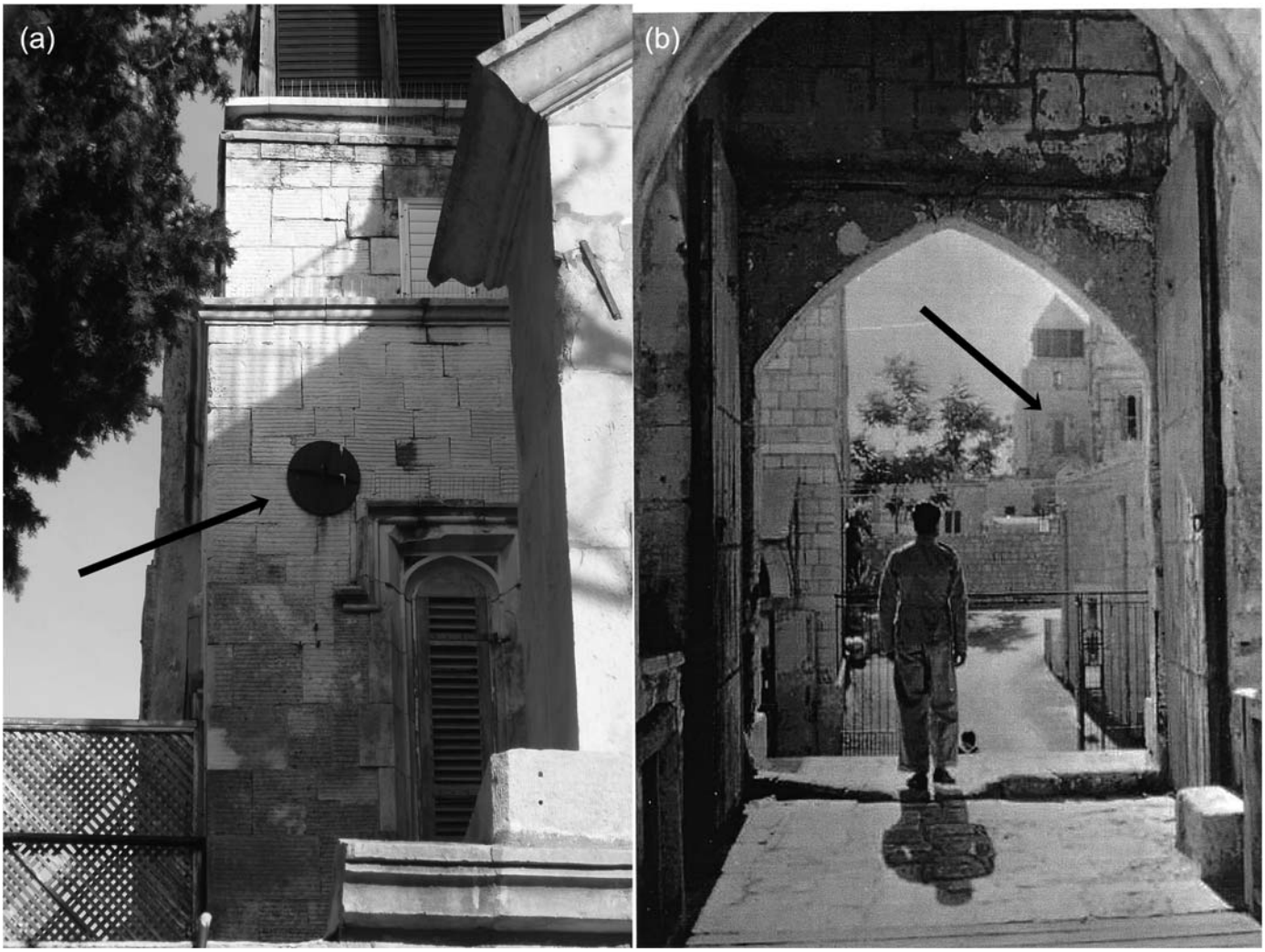
DISCUSSION AND CONCLUSIONS

The systematic comparison of old photographs taken prior and after the earthquake confirms that the appearance of numerous

▲ **Figure 8.** S-shaped anchors on the Alexander building, Christ Church: (a) April 2011, facing west toward the David Tower. (b) Jaffa Gate area (reprinted from American Colony Photograph Department, moat around the Tower of David, Jerusalem; G. Eric and Edith Matson Photograph Collection, Library of Congress, Prints & Photographs Division, 1898–1946 LC-DIG-matpc-08547). The date of the photograph is vague. The wooden cabinet at the entrance to the David Tower that was removed before 1925 implies, however, that the photograph was taken prior to the earthquake. (c) Air photo of the area from 1931 (reprinted from American Colony Photograph Department, Air views of Palestine. Jerusalem from the air (Old City). Jaffa Gate and Citadel, looking east along David Street, Jerusalem; G. Eric and Edith Matson Photograph Collection, Library of Congress, Prints & Photographs Division, 1931 LC-DIG-matpc-22146). The two S-shaped anchors are marked by arrows.

iron anchors is later than 1927 and is indeed associated with localities that were damaged during the Jericho earthquake. This methodology, tested in 11 localities, is found to be effective at differentiating the time range of the installation of the anchors and, consequently, single out those that were not part of the repairs made after the 1927 earthquake. The task of dating the installation of the anchors from photographs involves uncertainty because some of the photographs were neither taken shortly before nor close after the earthquake. Rather, the period between the date of photography and the actual earthquake occurrence spans from a few to nearly 30 years. In cases where we are not able to unequivocally determine whether a given photograph was taken before or after the event, we use information about other objects seen in the photograph to date them, as was exemplified in the case of the Catholicon's dome (Ⓔ Figs. S2, S3). Once we categorize the photographs as prior and after the event, their exact date is of less importance as (1) no other catastrophic event occurred during this period and (2) the claim that the anchors could have been installed before the earthquake as resistance to continuing deterioration in general of the building's structure could be rejected because all of the observed anchors appear only after 1927.

The question whether we could also attribute damage to other localities that were not photographed but presently



▲ **Figure 9.** Gobat building, Christ Church: (a) façade of the tower facing west with a round clamp installed (April 2011). (b) Bell tower, 1945 (reprinted with permission from Anonymous, Bell tower, Christ Church Jerusalem, Jerusalem; Zionist Archive, approximately 1945): no round clamp installation. Such clamps are modern and were probably installed after 1967.

contain installed anchors is highly important, in particular when mapping the spatial distribution of the damage. Of the six inspected anchor types, the most common anchors are the massive and short iron rails. In this group, seven localities were examined and in all of them the anchors were installed shortly after the earthquake. Thus, we conclude that other localities with such rails were probably damaged by the earthquake as well. Representative examples are the well anchored Imperial Hotel (Grand New Hotel) and Bikur Holim Hospital (Fig. 1). Similar association of the iron rods, X- and S-shaped anchors, however, is less decisive. Although we have examined three cases (one of each type) and successfully related the anchors to the 1927 earthquake, this sampling is not sufficient to conclude a linkage. Further cases are required prior to making a general association of such anchors to damage due to the earthquake.

All anchors types but the round clamps are found to be contemporaneous, as shown in the old photographs. Being contemporaneous, they are simple metal apparatus that were probably made by local smiths at the beginning of the twentieth century, prior establishment of the metal industry in Jerusalem (Ashbee, 1921). Thus, the categorization of the anchors by shape and size does not necessarily contribute information to determine their date of manufacture. On the other hand, the well-decorated shape of the round clamps implies a date of manufacture that was possible only a few decades after the earthquake, when iron casting became available. The absence of these clamps in photographs taken long after 1927 and their widespread use in post-1967 renovated buildings implies that the round clamps were installed only after the 1967 war during the rebuilding of the Jewish Quarter. Thus, such anchors do not serve as indicators of 1927 earthquake damage.

The use of the methodology presented here enables a determination of the spatial distribution of damage in the 1927 earthquake. In many cases, one can detect which part or wall of a structure was damaged. Thus, this technique can contribute additional damaged localities that are not mentioned in the

existing written sources that inventory the damaged structures in the 1927 earthquake (Avni, 1999). In fact, in light of many other anchors located in the Old and New City of Jerusalem, it reveals that the actual spread of damage was much wider than was previously shown. This conclusion improves our ability to discern the consequences of the 1927 earthquake in Jerusalem (Salamon *et al.*, 2010) and to detect failures of weak structures. This is of great importance in particular in the Old City, which contains a wealth of historical and architectural structures that should be preserved.

Iron anchors are also found in other cities and sites in Israel such as Akko, Tiberias, Nazareth, Petah Tiqva, Beit Jimal, Deir Hajleh, and Miqve Israel. Apparently, these localities were also reported to have been damaged during the 1927 Jericho earthquake (Avni, 1999, and references therein). The total number of damaged structures and some of their geographic locations, however, remains unknown. Therefore, the use of iron anchors assisted by the analyses of old photographs can also be utilized elsewhere to better delineate the damage due to past earthquakes.

ACKNOWLEDGMENTS

We wish to thank Yeri Rimon, Silvia Karpyoko (Israel Antiquities Authority), Maureen Greemshaw and David Pileggi (Christ Church), Anat Banin and Reuven Milon (National Zionist Archive), Nadav Man (Bitmuna), and Jean Michel Tarragon (Ecole Biblique Library) for their highly appreciated assistance in collecting the data. We wish to thank Ron Avni from the Ben Gurion University, Lili Arad from the Hebrew University, Hayim Goren from Tel Hai College, Shmulik Marco and Gideon Biger from Tel Aviv University, Tom Rockwell from San Diego University, Yaakov Schaffer, Yoel Bar-Dor, and David Kroyanker for their consultation and advice. We also acknowledge Yosepha Amdursky, Shabtai Zecharia, Keren Levi, Chen Barnet, Ahishalom Almog, and Tamar Sofer for their support and assistance and Beverly Katz for editing the text. Finally, we wish to thank the anonymous reviewer for his constructive review and comments.

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***Motti Zohar*[1]**
Rehav Rubin
Department of Geography
The Hebrew University of Jerusalem
Mount Scopus, Jerusalem 91905, Israel
mottiz@mscc.huji.ac.il

Amos Salamon
Geological Survey of Israel
30 Malkhe Israel Street
Jerusalem 95501, Israel

[1] Also at Geological Survey of Israel, 30 Malkhe Israel Street, Jerusalem 95501, Israel.