CONSTRAINS ON THE NEAR-SOURCE MOTIONS OF THE KOS-BODRUM 20 JULY 2017 MW6.6 EARTHQUAKE

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ABSTRACT

The Kos-Bodrum 20 July 2017 Mw6.6 earthquake ruptured an E-W normal fault dipping ~50° to the south. It caused destruction mainly in monumental structures in the city of Kos. We examine the source and rupture properties that shaped the near-fault ground motions. A key factor controlling the level of ground motions is the dip angle of the fault (between 30° to 60° in published mechanisms), alongside the dip polarity (to the north or to the south). The preferred slip model has two major asperities, with peak slip ~1.6m, located west and east of the hypocenter. The rupture propagated predominantly bilateral at a speed of 2.8 km/s. The ShakeMap shows an E-W spatial extension, in the mid-distance between the cities of Bodrum and Kos. The near-fault unique NS velocity time-series at Bodrum station, which is the fault normal direction, shows a late pulse, that is to say not at the beginning of the record, of period ~0.7s. In the absence of strong motion records in the city of Kos, we selected two near-fault horizontal time-series from the 2016 Norcia earthquake in Italy, as representative for the postulated bedrock motions. Adopting the preferred soil-profile and properties of Psycharis and Taflampas (2017) we perform 1D site response analysis, using the Bodrum and Norcia horizontal records as bedrock input motions, to estimate the surface motions. From all spectral comparisons, we conclude that the mainshock was characterized by enriched spectral ordinates for spectral periods >0.6s up to 2s, and that the effect of the soil in Kos city, is significant in this range.

Keywords: slip model; earthquake; seismicity; Bodrum; Kos

1. INTRODUCTION

The focus of the present work is the Kos-Bodrum earthquake of 20 July 2017 (UTC 22:31:11.7; Mw6.6), which occurred offshore, approximately in the mid-distance from the cities of Kos and Bodrum (Fig. 1) in southern Aegean Sea (Gökova Gulf). This has been the site of intense swarm-type activity in 2004-2005 with M5+ earthquakes and is considered amongst the most seismically active regions in coastal western Turkey. Tectonically the cross-border region between the eastern Aegean Sea islands and western Turkey accommodates ~N-S extension combined with shear motions from the operation of the segments of North Anatolia Fault (Chatzipetros et al. 2013, Tur et al. 2015). The earthquake occurred approximately one month after the Lesvos 12 June 2017 Mw6.4 event (Kiratzi, 2018). As the epicenters of both earthquakes are located offshore, the potential threat imposed to the nearby islands from the less well – mapped offshore faults, was revealed. The Kos-Bodrum mainshock caused 2 deaths and 120 injuries at the city of Kos, and 360 injuries in Turkey. The modern constructions in the city of Kos suffered no significant damage. It did cause though extensive damage and collapses in monumental constructions and in ancient columns and colonnades. Most fatalities were observed along the port and in the old town of the city of Kos, with partial collapse of old constructions from Ottoman era, minarets, churches, for example the St. Nicolas church and the castle of Nerantzia (ITSAK, 2017; Psycharis and Taflampas, 2017). The damage in the constructions on the Turkish side, at Bodrum, was limited.

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tsunami with a maximum height of 1.9 m was triggered by the earthquake and caused local flooding and some damage along the coasts of Kos and the Bodrum Peninsula (Ganas et al. 2017 and references therein).

Figure 1 summarizes the distribution of the aftershocks for the period July 1, 2017 – 31.12.2017 as derived from national centers. Aftershocks form three clusters (A, B and C in Fig. 1) which operated almost simultaneously. Note the diminish of aftershocks east of mainshock where the major slip is expected to occur, as later shown. A strong aftershock (Mw4.7) occurred on 21 July (Table 1) underneath the city of Kos, which probably added to the damage pattern. The dip polarity of the fault is controversial; it was resolved as north dipping (Ganas et al. 2017) and as south dipping (Saltogianni et al. 2017; Tiryakioğlu et al., 2018). We performed a number of along dip cross-sections (not shown here) in an attempt to resolve its dip. Unfortunately, no convincing sections were obtained, taking into account the uncertainties in the epicenters, and especially in the focal depths, which is the least well resolved parameter during routine seismicity analysis. In fact, from Table 1 a strong variability in the angle of the dip of the fault, both for the south and north dipping nodal planes, is obvious. All solutions converge though that the causative fault is normal (rake ~ -90°) that strikes ~E-W. The north dipping planes converge to a more moderate deep compared to the south dipping planes which have an average value ~50°, which is a common dip angle for normal faults in the broader Aegean Sea area.

The scope of the present work is to examine the source properties of the mainshock that played an important role in the damage pattern, especially in the city of Kos. We opt for a stepwise approach of two steps: a) we invert seismic waveforms to constrain the location of the fault, the location of the slip patches in respect to the cities of Kos and Bodrum, the presence of directivity if any, the rupture speed and the slip duration; b) we perform an analysis of the strong motion records of the mainshock and seek suitable motions from other similar earthquakes, to get estimates of the intensity of ground motion at
the city of Kos, at bedrock and subsequently to the surface. In this part, we build upon the results of Psycharis and Taflampas (2017). Finally, we discuss the possible source properties that affected the ground motions.

Table 1. Published focal mechanisms for the mainshock and for the Mw>4.7 aftershocks of the sequence.

<table>
<thead>
<tr>
<th>Date</th>
<th>Origin time</th>
<th>Lat.</th>
<th>Long.</th>
<th>h (km)</th>
<th>North dipping fault</th>
<th>South dipping fault</th>
<th>Ref</th>
</tr>
</thead>
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<tr>
<td>20170720</td>
<td>22:31:11.7</td>
<td>36.9643</td>
<td>27.4332</td>
<td>7</td>
<td>6.5</td>
<td>275</td>
<td>41</td>
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<td></td>
<td></td>
<td>15</td>
<td>6.7</td>
<td>290</td>
<td>26</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12*</td>
<td>6.6</td>
<td>275</td>
<td>36</td>
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<td>11</td>
<td>6.7</td>
<td>296</td>
<td>49</td>
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<td>6.6</td>
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<td>35</td>
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<td>12</td>
<td>6.6</td>
<td>285</td>
<td>39</td>
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<td>average</td>
<td>20170721</td>
<td>17:09:50.9</td>
<td>36.8900</td>
<td>27.3152</td>
<td>8</td>
<td>4.7</td>
<td>271</td>
</tr>
<tr>
<td>20170722</td>
<td>07:42:19.9</td>
<td>37.0283</td>
<td>27.6052</td>
<td>4</td>
<td>5.2</td>
<td>290</td>
<td>64</td>
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<tr>
<td>20170811</td>
<td>11:16:53.5</td>
<td>37.1298</td>
<td>27.6790</td>
<td>6</td>
<td>4.9</td>
<td>274</td>
<td>53</td>
</tr>
<tr>
<td>20170814</td>
<td>02:43:49.3</td>
<td>37.1527</td>
<td>27.7037</td>
<td>8</td>
<td>4.8</td>
<td>252</td>
<td>37</td>
</tr>
</tbody>
</table>

* depth fixed; 1: Saltogianni et al. (2017)

2. SLIP MODEL OF THE MAINSHOCK

2.1 Data and Methods

We retrieved and processed three component broad band and strong motion complete waveforms from regional stations located in Greece and Turkey. We used 18 components in the inversion, whose waveforms, prior to the inversion, were baseline corrected, tapered, corrected for the instrument response, converted to displacement (cm), band pass filtered between 0.05 to 0.08 Hz, and re-sampled to 1 Hz. We used our library of precomputed Green’s functions, by the frequency-wave number method (Saikia, 1994) and the 1D velocity model of Novotný et al. (2001), which were also filtered, between 0.05 and 0.08 Hz, as the real data. The slip model was calculated using a non-negative least-squares inversion with simultaneous smoothing and damping (Dreger and Kaverina, 2000; Kaverina et al. 2002). This method is suitable to resolve the fault plane, from the two nodal planes.

2.2 Finite fault slip model parameterization

Initially both nodal planes were tested as the causative fault, in order to examine the goodness of fit, measured as the percentage of the total Variance Reduction (VR). For the south dipping plane, the VR=75% compared to VR=66% for the north dipping plane. Thus, a south dipping plane provides better fit to the data, and is in accordance with the seafloor morphology (Ocakoğlu et al. 2018). Additionally, we tested all the published focal mechanism solutions (Table 1) for the mainshock. The best fit was obtained for the AUTH solution, which was adopted in the inversions. The fault model is parameterized as a rectangle, with dimensions 50 km × 25 km, discretized into 1250 subfaults, each with a dimension of 1 km × 1 km. The dimensions of the fault are approximately double of those expected, to ensure that the fault model is large enough to accommodate unilateral rupture in any direction. The slip rise time is also assumed to be constant, has the shape of an isosceles triangle with a duration of 1s consistent with Somerville et al. (1999). We grid searched a range of rupture velocities, between 2.2 km/s and 3.6 km/s, and found that 2.8 km/s (which corresponds to ~0.8 of the shear wave velocity at the hypocenter depth) was better explaining the data and provided the best percentage of the Variance Reduction.
2.3 Preferred slip model for the south dipping plane

Figure 2 shows our preferred slip model with two shallow slip patches, located west and east of the hypocenter. The propagation of the rupture was predominantly bilateral. The strongest slip occurred east of the hypocenter, at the area which is practically void from aftershocks. For this model parameterization, which resulted in good variance reduction (VR 75%), the peak slip is 162 cm, the average slip within the asperities is ~80 cm, the average slip of the model is 50 cm, and the resolved moment is \( Mo = 1.214e26 \text{ dyn-cm} \) (Mw 6.65).

The dimensions of the causative fault, as defined by the area that slipped, are \( \sim 30 \text{ km} \times 15 \text{ km} \), along strike and dip, respectively, when measured within the 30 cm slip contour (~20% of peak slip). These dimensions are in accordance with those expected from empirical scaling relations for normal faults (Wells and Coppersmith, 1994). The slip model obtained here, shares part of the features observed in other published models (Saltogianni et al. 2017; Tiryakioğlu et al. 2018) which are based on teleseismic data and geodetic data.

Figure 2. Left: Preferred slip model for the 20 July 2017 Kos-Bodrum mainshock, with two slip patches, east and west of the hypocenter. The area that slipped has dimensions 30 km ×15 km along strike and dip, respectively. On the right, the moment rate function implies ~9s of total duration and 1.75s dislocation rise time. Right: Surface projection of the slip model and of the fault plane (rectangle). The city of Kos lies on the hanging wall, whereas the city of Bodrum on the footwall.

Assuming a circular fault in a whole-space, of radius \( r \), for the resolved seismic moment, \( Mo \) and for 30 km × 15 km fault area, the calculated Brune-type stress drop, \( \Delta \sigma = \frac{7Mo}{16r^3} \) is of the order of 3.1 MPa (31 bars), which fits the commonly quoted average values (1-6 MPa) for the Mediterranean area (Konstantinou, 2014).

2.4 Sensitivity of the slip model to the dip angle of the fault

The dip angle of the fault is a crucial parameter and the published solutions show variability. We performed sensitivity analysis to examine the effect of the dip angle on the slip model. Specifically, we tested steeply and gentle dipping fault planes, both for the case of a south dipping plane and for a north dipping plane.

The results are summarized in Figure 3. A stable feature of the slip models is the double asperity pattern. The peak slip values change within the models, from 2 m to 3.5m, even though the average values are of order of 50-60 cm in all cases. Using the Variance Reduction (%VR) as proxy for the goodness of fit, we may conclude that a north dipping fault is best modeled with a moderate (35°) dip angle, whereas a south dipping fault is best modeled with a steeper (~50°) dip angle. This observation is also reflected in the, so far, relative publications which favor the north or south dip of the fault plane.
Figure 3. Sensitivity analysis regarding the dip angle of the fault; end members of dip angles (Table 1) are examined both for south and north dipping faults. The strike/dip/rake of the fault assumed during the inversions together with the %VR are shown in the figure. Note that the slip scales are variable among the plots.

2.5 ShakeMap

The preferred slip model (Fig. 2) was used to perform forward modeling in order to deterministically calculate the distribution of peak ground velocities (PGVs) in the near field. We computed full velocity waveforms up to 2 Hz at a grid of nodes 50 km x 50 km, with a spacing of 0.05°, centered at the epicenter location. At each node we calculated the peak ground velocity (PGV), as the arithmetic mean of the peak velocities of the two horizontal synthetic components.

We contour the peak values using a step of 20 cm/s. As most of the affected region is offshore, we present the results, without including the site-effect in the calculated synthetic motions. The common approach to correct for this effect is using the topography gradient as proxy for the shear-wave velocity at the first 30 m ($V_{s30}$).

The distribution of PGVs (Fig. 4) shows that the most affected region is the coastal region of southern western Anatolia and it mainly extends southwards from Bodrum. The ShakeMap reflects the two-lobe slip pattern and the bilateral rupture propagation. It is worth noting also that east of the epicenter the PGVs show a steeper gradient, compared to the west. The predicted velocities at Bodrum are in accordance with the recorded peak velocities at the accelerograph station (Table 2), which is located on stiff soil conditions.
Figure 4. ShakeMap: Velocity horizontal time-histories at each node (small black triangles) of a grid covering the region, are calculated from the slip model (Fig. 2) using forward modeling. The arithmetic mean of the peak velocities is contoured here to show the decay of ground motions and most affected region south of Bodrum. Note the location of Bodrum, Gulluk and Datca strong motion stations.

3. CHARACTERISTICS OF NEAR–FAULT RECORDED GROUND MOTIONS

The Kos-Bodrum mainshock was recorded by a number of near-source accelerograph stations in Turkey (Table 2). We do have a near-fault record at Bodrum, but we do not have a record at Kos, due to malfunction of the accelerograph. The Bodrum horizontal records (Fig. 5) clearly show that the intensity of ground motion is stronger in the N-S direction, that is, along the fault normal (FN) component.

Table 2. Peak values (corrected) at accelerograph stations (AFAD network in Turkey).

<table>
<thead>
<tr>
<th>Station</th>
<th>latitude °N</th>
<th>longitude °E</th>
<th>NS cm/s²</th>
<th>EW cm/s²</th>
<th>UD cm/s²</th>
<th>NS cm/s</th>
<th>EW cm/s</th>
<th>UD cm/s</th>
<th>Distance (km)</th>
<th>Vs30 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>BODRUM (4809)</td>
<td>37.0330</td>
<td>27.4399</td>
<td>162.4</td>
<td>105.3</td>
<td>88.0</td>
<td>23.0</td>
<td>9.1</td>
<td>7.3</td>
<td>8</td>
<td>747</td>
</tr>
<tr>
<td>GULLUK (4817)</td>
<td>37.2401</td>
<td>27.6031</td>
<td>78.3</td>
<td>59.5</td>
<td>32.0</td>
<td>5.5</td>
<td>2.5</td>
<td>2.8</td>
<td>34</td>
<td>n/a</td>
</tr>
<tr>
<td>DATCA (4812)</td>
<td>36.7122</td>
<td>27.6880</td>
<td>38.7</td>
<td>42.8</td>
<td>32.0</td>
<td>3.4</td>
<td>4.8</td>
<td>2.4</td>
<td>36</td>
<td>n/a</td>
</tr>
</tbody>
</table>

We calculated the spectrogram of the Bodrum N-S acceleration time series, using a sliding time window of 0.05s to examine the spectrum over a frequency range (Fig. 5b). It is clear that the spectral power occurs 10s to 13s after the beginning of the record, at frequencies in the range 1Hz – 2 Hz (periods 0.5s to 1s) and the peak occurs at 1.4 Hz (T=0.7s). This is also reflected in the NS velocity record of Bodrum which shows a late pulse (Fig. 5a second panel), that is a pulse that is not observed at the beginning of
the time-series, and thus cannot be strictly attributed to directivity effects, but can be attributed to site response (geotechnical effects) among other factors. We used an empirically calibrated algorithm based on the continuous wavelet transform (Baker 2017) to examine if it can be flagged as a pulse-like record. With this algorithm we did not detect any impulsive ground motion attributes.

Figure 5a. Near-fault horizontal time-histories (GMT 22:31:07) at Bodrum station (Table 2). Linear baseline correction and a 2nd order Butterworth filter with low-pass corner at 30 Hz and high-pass at 0.04 Hz was applied. Three upper panels for the N-S component, three lower panels for the E-W component.

Figure 5b. Spectrogram [amplitude (color scale) vs frequency vs time] of the NS Bodrum acceleration time-series. The peak spectral power occurs at 10s - 13s after the beginning of the record (GMT 22:31:07) at frequency 1.4 Hz (period 0.7s).

Figure 6 compares the elastic PSA and PSV response spectra, (5% damping value), of those components which recorded the strongest ground motions. Peak acceleration spectral values are observed for low periods (~0.18s) with a second peak around 0.3s. The increase of velocity spectral ordinates at period ~0.7s, is most pronounced in the FN Bodrum PSV spectra, as has been already observed by Psycharis and Taflampas (2017), and weaker in the Gulluk FN spectrum, but still visible. The Datca horizontal
velocities are enriched at even higher spectral periods (1.2s to 2.2s).

Figure 6. Elastic response spectra (5% damping factor), of acceleration (top) and velocity (bottom) for the component which recorded the highest intensity of ground motion for each station (see Table 2).

3.1 Postulated bedrock horizontal ground motions at Kos city

To estimate the level of ground shaking at Kos town, at a distance ~15 km from the epicenter, and explain the damage pattern as described in field surveys (ITSAK, 2017; Psycharis and Taflampas, 2017), is not straightforward. For one thing, the position of the fault itself and the choice of the dip polarity of the fault plane, towards south or north, is very crucial, to account for hanging-wall or foot-wall effects. Additionally, the value of the dip angle (moderate or steep) is equally important. In fact, experimental dynamic rupture simulations indicate that near-fault fault-normal (FN) peak velocities are sensitive to fault dip (O’Connell et al., 2007). During these simulations, in homogeneous and weakly heterogeneous media with faults dipping less than ~50°, the maximum fault-normal peak velocities occurred on the hanging wall. However, for fault dips greater than ~50°, maximum fault-normal peak-horizontal velocities occurred on the footwall. Moreover, normal faults often juxtapose a low-velocity hanging-wall sedimentary basin against relatively stiff footwall rocks. In the presence of strong velocity contrasts, between the sedimentary basin and the footwall material, the fault-normal peak velocities can be significant in the footwall, and even larger in the hanging wall. In summary, to adopt simple amplitude parameterizations based on the hanging wall (HW) and/or footwall as well as the fault normal and/or fault parallel, often used in ground motion prediction models, may not be appropriate for some faults with dips > 50° (O’Connell et al., 2007 and references therein).

In the absence of recorded ground motion in Kos city, we searched the Italian (ITACA v2.3) strong motion database (Luizi et al. 2016) for suitable records, from similar earthquakes in the Mediterranean, in an attempt to obtain upper and lower bounds. To this end, we specifically searched for pulse-like and
non-pulse like records, from normal faulting events, of comparable magnitude (6.5 – 6.7), from comparable epicenter-site (Fig. 7a) geometrical predictors (Kaklamanos et al. 2011). That is to say for comparable epicentral distance, Repi (<15 km), for Joyner-Boore \( R_{JB} \) distance equal to zero to account for hanging-wall effects (Abrahamson and Somerville, 1996) and up to ~3 km, \( R_{rup} \) < ~10 km, and for Eurocode 8 (CEN, 2003) class B site conditions. The best matches (Table 3) were retrieved from the 30 October 2016 Mw6.5 Norcia earthquake in central Italy (Luzi et al., 2016). The focal depth of this event is ~9 km, comparable to the Kos-Bodrum mainshock, its focal mechanism is pure normal fault (strike 151°, dip 47°, rake -89°), the fault area is comparable, e.g. 26 km × 14 km along strike and dip, respectively (Luzi et al., 2017). These time-series have been processed exactly as we have processed the Bodrum records.

Table 3. Selected suitable records from the 20161030 Mw6.5 Norcia earthquake, as representative bounds for the intensity of bedrock ground motions at the city of Kos.

<table>
<thead>
<tr>
<th>Station</th>
<th>Repi km</th>
<th>Rjb km</th>
<th>Rrup km</th>
<th>PGA cm/s²</th>
<th>PGV cm/s</th>
<th>pulse-like</th>
<th>EC8</th>
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<tbody>
<tr>
<td>T1214</td>
<td>11.4</td>
<td>0</td>
<td>4.54</td>
<td>633 UD</td>
<td>54</td>
<td>Yes</td>
<td>B*</td>
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<tr>
<td>T1216</td>
<td>9.9</td>
<td>3.06</td>
<td>9.25</td>
<td>277 NS</td>
<td>16</td>
<td>No</td>
<td>B*</td>
</tr>
</tbody>
</table>

To verify the pulse-like attributes in the ground motion of the horizontal waveforms at T1214 we applied the previously mentioned algorithm of Baker (2007) and we extracted the pulse (Fig. 7b). Thus, in the horizontal velocity records both the hanging wall (\( R_{jb} = 0 \)) effect and the near-fault pulses from forward directivity and the radiation pattern of the source, are included.

Figure 7. a) Geometry of site-epicenter discussed in the text b) Validation of the pulse-like T1214 horizontal velocity record of the 20161030 Mw6.5 Norcia earthquake selected as proxy for the intensity of ground motion at Kos city. The extracted pulse duration (or pulse period) is \( T_p = 2.7s \) and the pulse azimuth is 259°.

We compare the elastic response spectra (5% damping) of the EW component of these suitable motions, which is approximately the FN component, with the Bodrum FN component, in Figure 8. This comparison is meant to show the intensity of motions from a similar earthquake in the near-source region, and does not imply that the ground motions in Kos city would share the same characteristics. From this comparison, some interesting features of the spectral content of the Kos-Bodrum mainshock can be deduced. For one thing, all spectra show that for periods below ~0.6s the Bodrum FN component better matches the non-impulsive T1216 EW time-series. The most striking characteristic is the increase in spectral ordinates for periods in the range 0.6s – 1.2s in the FN Bodrum component. These observations confirm those of Psycharis and Taflampas (2017) regarding the strong late pulse of period ~0.75s that is the dominant characteristic of the FN Bodrum record. Assuming that the Norcia records consist representative bedrock ground motions at the city of Kos, then the pulse-like and non-pulse records may provide indicative bounds. For example, the more conservative T1216 EW record shows PGA ~ 0.8g at short periods (<0.2 s) and PGA ~0.4g – 0.6g for periods in the range 0.2s – 0.4s.
Figure 8. Elastic response spectra (damping factor 5%) comparisons between the Bodrum NS (FN component) and the horizontal records from the 2016 Mw6.5 normal-faulting Norcia earthquake in central Italy (Table 2), which are considered to represent upper and lower bounds of the intensity of motions at Kos city.

3.2 Postulated surface horizontal ground motions at Kos city

In an attempt to calculate the postulated horizontal motions at the surface of the city of Kos, we performed 1D equivalent linear site response analysis using STRATA (Kottke and Rathje, 2009). We build upon the analyses of Psycharis and Taflampas (2017) and we adopted their most probable soil-profile, that is their C2 soil profile (EC8 classification C/E, \( V_{S,30}=267 \) m/s) and their site-properties. This profile accounts for a homogeneous soil layer, of loose to medium stiffness, overlying the bedrock. In our case, as input motions we used the Norcia EW horizontal time-series and the Bodrum NS record (scaled by a factor of 2.5 as they suggest to include the HW effect). From the above realizations we obtained the surface time-histories for all input motions. Figure 9 compares the corresponding elastic response spectra of acceleration, and the spectral ratio, which is the ratio of the surface spectral accelerations divided by the bedrock spectral accelerations.
Figure 9. Top: Elastic response spectral accelerations (5% damped), at the city of Kos, for the soil-profile C2 (Psycharis and Taflampas, 2017) using as bedrock input motions the Norcia earthquake records and the Bodrum NS component (see text). Bottom: Ratio of surface spectral acceleration/bedrock spectral acceleration. Note the deamplification at spectral periods < ~0.2 s in all motions, the strong amplification for spectral periods in the range 0.5 to 1 s in the Norcia motions. Note that the Bodrum record shows an amplification 1.5-1.8 for a broad range of spectral periods (~0.6 s – 2.0 s).

The soil effect is better seen from the spectral ratios. The analysis shows a deamplification at short spectral periods and significant amplification (above 1.5) in the period range 0.5 s to 1.0 s. At the same time, the Bodrum horizontal component, exhibits the same deamplification for periods less than ~0.2 s and amplification of a factor 1.5 to 1.8 in a broad range of spectral periods, approximately from 0.5 s to 2.0 s, partly explaining the damage pattern especially of the long period monumental structures.

4. CONCLUSIONS

The Kos-Bodrum 20 July 2017 Mw6.6 mainshock ruptured an E-W striking, offshore normal fault, that dips to the south at ~50°±9°. The dimensions of the fault are 30 km along strike and 15 km along dip. We performed an analysis of the key factors that contributed to the intensity of ground motions in the near-field and shaped the damage pattern, especially to the monumental structures at the city of Kos. To do so, we started from the seismic source, to constrain first of all the location of the slip onto the fault plane and its amplitude. One of the key parameters that control the slip model and the damage pattern is the dip angle (shallow dip vs steeper dip) and the polarity of the dip (to the south or to the north). The sensitivity analysis showed the robust features of the slip models, which is the predominantly bilateral
propagation and the double asperities. These test inversions provided the best fit to the data for a south dipping fault with a steep angle (~50°). However, acceptable fits are obtained for the case of a north dipping fault but for a smaller dip angle (~35°). We prefer the south dipping fault because it is in accordance with the morphology and recent research (Ocakoglu et al 2018). The peak slip of the model is 1.6 m, while the average slip (within the asperities) is ~80 cm.
- The mainshock produced a unique near-fault record at Bodrum station, which is located on stiff-soil, and on the footwall. The N-S component, that is the fault-normal component, recorded the highest intensities of the ground motions. The spectrogram of the acceleration time-history of this record, showed that the peak spectral power occurs at 1.4 Hz (T=0.7s). This is also pronounced on the PSV response spectra of the same component (late pulse at period ~0.7s).
- The city of Kos lies on the hanging-wall of the fault and on alluvial deposits. In the absence of records at Kos, we sought suitable bedrock motions from similar earthquakes, using tight constraints discussed in the text, we found two near-source records from the 2016 Mw6.5 Norcia earthquake. We performed 1D site response analysis, using as input motions the Norcia and Bodrum records, to calculate the motions at the surface. We build upon the work and the results of Psycharis and Taflampas (2017) and we confirm the strong pulse at periods 0.6s -0.8s, and the strong amplification of surface horizontal motions, compared to the bedrock ones, in long periods.
- The damage pattern at the city of Kos, mainly in monumental constructions, should be sought in the combined effect of (a) source spectral content (peak amplitudes at T~ 0.6s-0.8s), (b) proximity to the slip patches, (c) the hanging wall effect, (d) the site-effect, and maybe due to strong heterogeneities in crustal velocities.

5. ACKNOWLEDGMENTS

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6. REFERENCES


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