The cause of heavy damage concentration in downtown Mashiki-cho inferred from observed data and field survey

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To understand the cause of the damage during the mainshock of the 2016 Kumamoto earthquake sequence, we carried out field survey from 29 April through May 1, in Mashiki Town, including microtremor observation. We have extracted sufficient information from which we can infer the cause of the heavy damage concentrated in Downtown Mashiki, where strong motions with JMA seismic intensity of 7 were observed.

First the fundamental features of the structural damage in the damage concentrated area (DCA) in Downtown Mashiki were summarized. The damage concentration starts from the west of the National Highway R.443 and extends to the east of the Prefectural Road R.235, about 1.5km to 2km in the east-west direction. In the north-south direction it spreads about plus/minus 300m on both sides of the Prefectural Road R.28. The main features need to report are as follows:
1) inside DCA, not only old (and so weak) wooden houses but also new and reinforced houses were damaged;
2) there are many old buildings that have successfully survived outside of the heavy damage lines in the east-west (EW) direction;
3) the damaged houses look aligned to some lateral extent (50 to 100 m) in EW direction;
4) The deformed direction of the collapsed or heavily inclined houses were mostly in EW direction (attached photo). Overturning direction of tombstones were also in EW direction;
5) Almost always significant ground deformation, failure, and cracks can be seen in the paved roads crossing the above damage lines.

Next, inside DCA we measured microtremors covering about 700m by 1km with about 100m intervals. Horizontal-to-Vertical Spectral Ratio of Microtremors (MHVRs) at three selected sites deployed at the northern end, in the center, and at the southern end of DCA were compared. The observed MHVRs share the common peak in the vicinity of 2 to 3Hz, with the level of 4 to 5. This MHVR characteristics suggest that the subsurface structure may have moderate impedance contrast at certain depths but that the differences in MHVRs at these three stations are so small that it is impossible to explain DCA creation by the spatial difference of soil structures below.

Finally by using the observed strong motion records at the Mashiki Town Office and a nonlinear response analysis model, which was calibrated to reproduce observed damage ratios of wooden houses during the 1995 Kobe earthquake, we calculated the estimated damage ratios at the Mashiki Town Office. We found that more damage would have occurred in the EW component than in the NS component. We also found that the calculated damage ratio was only 30% at most. This means that the observed ground motions in DCA were not surprisingly strong to wooden houses.

Based on these survey results, the mainshock hypocenter location, and AIST GSJ information on mapped active faults and InSAR on their web site, we may conclude that DCA in Mashiki was created by the complex interaction of both strong ground motions and crustal deformation associated with the fault movement and subsequent ground failures, rather than the simple strong shaking alone. The

reason for this conjecture is as follows:
1) The ground motion there was not strong enough to create such a large damage as had been observed.
2) The damage in the fault-parallel direction was dominant, rather than the fault-normal direction which is supposedly stronger.
3) The damage lines were continuous in the EW direction only. Ground deformation, failure, and cracks were observed in the roads across these damaged lines.
4) Inside of the damage lines some newly-constructed houses were damaged, while outside of the damage lines even old houses could sometimes survive with the minor damage.
5) It is not likely to have strong velocity variations beneath DCA.
6) The active fault map by GSJ shows a branching fault along the Prefectural Road R.28 (Kiyama fault). The western end of Kijima fault is the eastern end of DCA. This is so because in DCA the fault displacements associated with the earthquake have been distributed in a wide area. Variation of crustal movement in InSAR contours also shows spreading motions there including DCA.
7) The mainshock hypocenter seems to be on the far western extension of Kijima fault. We can confirm from the InSAR contours that Kijima fault actually corresponds to the northern end of the crustal deformation there.

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