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Proposal of median distances for ground motion prediction equations

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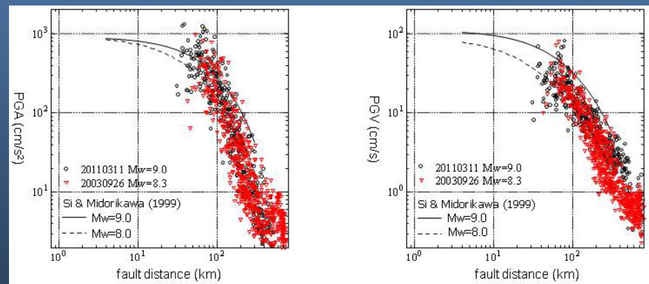
Introduction (1)

- In comparing the existing ground motion prediction equations (GMPEs) with the observed record of the 2011 Tohoku earthquake, it is becoming clear that the results of the equations may vary significantly according to which definition of distance is applied.

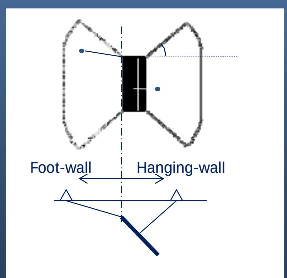


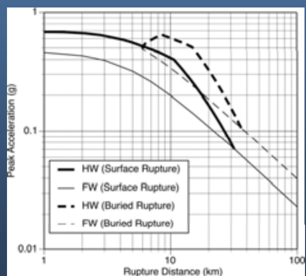
Peak Ground Accelerations Peak Ground Velocities

For example, the ground motions of the 2011 M_w 9.0 Tohoku earthquake look only equivalent to those from the 2003 M_w 8.3 Tokachi-oki earthquake, if we use fault distances.

Introduction (2)

- The problems originating from the definition of distances, such as the hanging wall effect, are also becoming more evident. This study created and defined a new term called "median distance" and produced a new GMPE by using the same set of data as Si and Midorikawa (1999). With this equation, we conducted a preliminary study to analyze the advantages which can be derived from this definition.

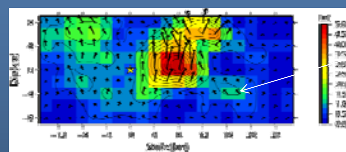




Hanging wall effect (*e.g.*, Abrahamson and Somerville, 1996; Abrahamson and Silver, 2008; Campbell and Bozorgnia, 2008)

Alternatives for `fault distance'

- Equivalent Hypocentral Distance (Ohno et al., 1993)
  for earthquakes where strong motion generation areas (SMGAs) coincide with asperities (large slip areas)

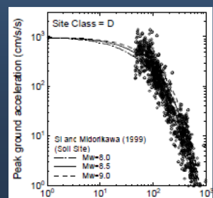


M_{0i}

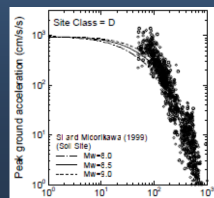
$$X_{eq}^{-2} = \sum_{i=1}^{n} M_{0i}^{2}(f) X_i^{-2} / \sum_{i=1}^{n} M_{0i}^{2}(f)$$

2008 Iwate-Miyagi Nairiku earthquake

- Shortest Distance from SMGAs (Midorikawa et al., 2012)
  for earthquakes where SMGAs do not coincide with asperities

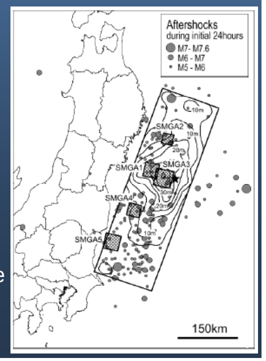


fault distance



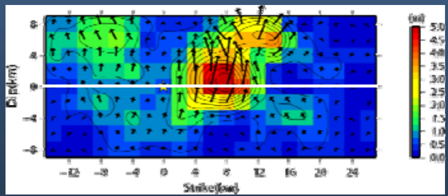
shortest distance from SMGAs

2011 Tohoku earthquake



However, a distribution of slips or SMGAs is required, but it cannot be obtained in advance to an earthquake.

- Earthquake source faults, in many cases, are configured to place main SMGAs at their centers. Their planes tend to lengthen in the along-strike direction and SMGAs tend to diversify towards the same direction. However, when observed towards the down-dip direction, they can be approximated to be located near the center. Therefore, we defined the “median fault line” as the straight line extended from the midpoint of the fault plane in the along-strike direction, and defined “median distance” as the shortest distance from an observation point to the “median fault line”.



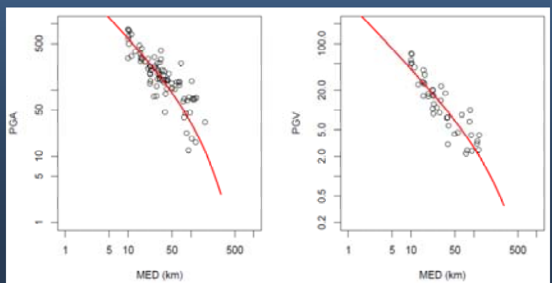
2008 Iwate-Miyagi Nairiku earthquake (Hikima et al., 2009)

Data

NO.	Earthquake	Date	M_w	Depth	Number of recordings: Peak acceleration	Number of recordings: Peak velocity	Fault Type	Weight	Reference
1	Off Tokachi	1968.05.16	8.2	15	10	10	Inter-plate	C	1, 2
2	Off Nemuro Pen.	1973.06.17	7.8	25	6	4	Inter-plate	C	1, 2
3	Near Izu Oshima	1978.01.14	6.6	7	8	12	Crustal	C	1, 3
4	Off Miyagi Pref.	1978.06.12	7.6	37	13	10	Inter-plate	C	1
5	East off Izu Pen.	1980.06.29	6.5	7	19	16	Crustal	B	1, 3
6	Off Urakawa	1982.03.21	6.9	25	19	9	Crustal	C	1, 2
7	Nihonkai-Chubu	1983.05.26	7.8	6	21	17	Inter-plate	C	1
8	Off Hyuganada	1984.08.07	6.9	30	9	8	Intra-plate	C	4,5,6,7
9	Central Iwate Pref.	1987.01.09	6.6	73	10	5	Intra-plate	C	4,8,9
10	Northern Hidaka Mt.	1987.01.14	6.8	120	16	9	Intra-plate	C	4,9,10
11	East off Chiba Pref.	1987.12.17	6.7	30	173	47	Crustal	A	1,3,11
12	Off Kushiro	1993.01.15	7.6	105	51	21	Intra-plate	B	4,11
13	Off Noto Pen.	1993.02.07	6.3	15	21	5	Crustal	C	4,13,14,15,16,17
14	Southwest off Hokkaido	1993.07.12	7.7	10	52	18	Inter-plate	B	4,12,18
15	East off Hokkaido	1994.10.04	8.3	35	41	17	Intra-plate	B	4,18,19,20
16	Far off Sanriku	1994.12.28	7.7	35	83	30	Inter-plate	B	4,22,23,24
17	Hyogo-ken Nanbu	1995.01.17	6.9	10	85	47	Crustal	A	4,25
18	Off Hyuganada	1996.10.19	6.7	25	106	67	Inter-plate	A	4,26
19	Northwestern Kagoshima Pref.	1997.03.26	6.1	6	121	68	Crustal	A	4,27,28
20	Northwestern Kagoshima Pref.	1997.05.13	6.0	7	121	64	Crustal	A	4,27,29
21	Northern Yamaguchi Pref.	1997.06.25	5.8	10	152	59	Crustal	A	4,27,30

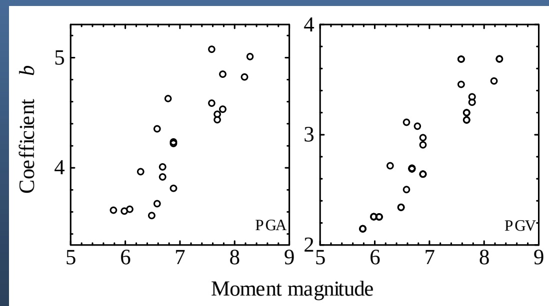
Construction of GMPEs (first stage)

- The relations between median distances and PGAs or PGVs recorded during the 1995 Kobe earthquake indicate no saturation at close distances. Because this confirms the usefulness of median distance, we used the equation: $\log A = b - \log X_{med} - k X_{med}$ (A: PGA or PGV, X_{med}: median distance) as the first-stage regression model for the GMPE using median distances. We applied this regression model to each earthquake and calculated the value of coefficient *b.* In order for the ground motion data at close distances to be reflected strongly, we analyzed by giving a weight of 8 for distances less than 25 km, 4 for 25 to 50 km, 2 for 50 to 100 km and 1 for over 100 km.



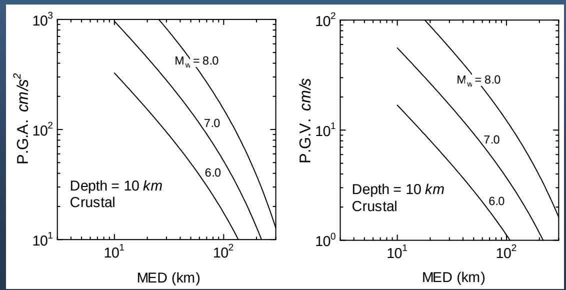
Construction of GMPEs (second stage-1)

- The coefficient *b* in the first stage regression model of the 1995 Kobe earthquake shows a strong correlation with moment magnitude (M_w). In addition, the large variation of *b* remained even at the same M_w and it became obvious that *b* is influenced by other variables than M_w.



Construction of GMPEs (second stage-2)

- Therefore, as in Si and Midorikawa (1999), we performed the second stage of regression analysis by applying the model: (D: focal depth, S_i: earthquake type, e: constant term, e: standard deviation, a, h, d_i: regression coefficient). S_i is a dummy variable and is nonzero only when it is any one of the crustal, interplate and intraplate type earthquakes. The results of the analysis indicate, in the same way as Si and Midorikawa (1999), that PGA and PGV tend to rise in the case of intraplate earthquakes, or when the focal depth is great. The tendency of such rise is stronger for PGA than PGV.

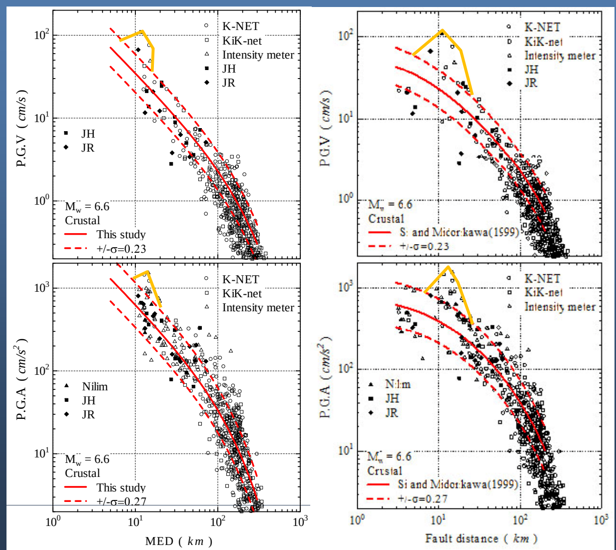


Comparative analyses of the obtained GMPEs

- We have conducted comparative analyses of the GMPEs derived in this study with PGAs and PGVs observed in the 2004 Chuetsu, 2007 Chuetsu-oki, 2008 Iwate-Miyagi Nairiku, and 2011 Tohoku earthquakes.
- We used strong motion data obtained by K-NET and KiK-net of NIED, JMA and TEPCO. We have applied 0.1 to 10 Hz band pass filter and determined the values of PGAs at the ground as in Si and Midorikawa (1999).
- Further, we obtained the velocity waveforms by integrating the acceleration waveforms at stations where AVS30 is estimated, and determined the values of PGVs on the basement, with relations of amplification factors and AVS30 as in Si and Midorikawa (1999).

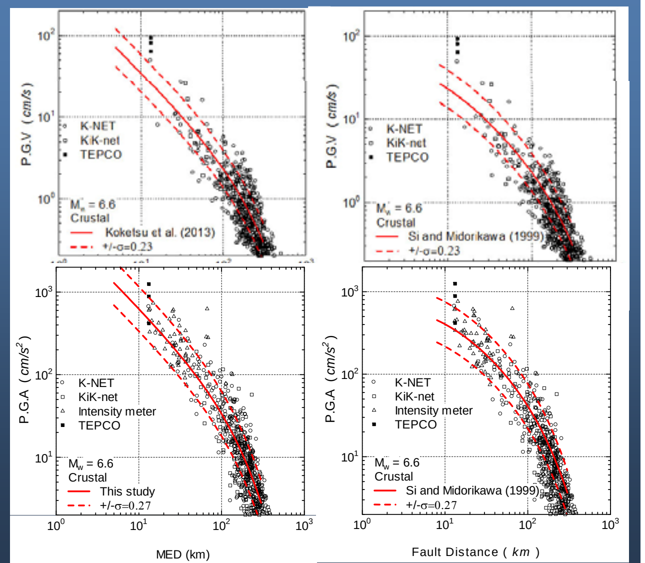
2004 Chuetsu earthquake

- The comparative analysis for the 2004 Chuetsu earthquake not only confirms the validity of the GMPEs derived in this study, but also that the hanging wall effect is resolved to some extent compared to the results of the equations of Si and Midorikawa (1999) using fault distances.



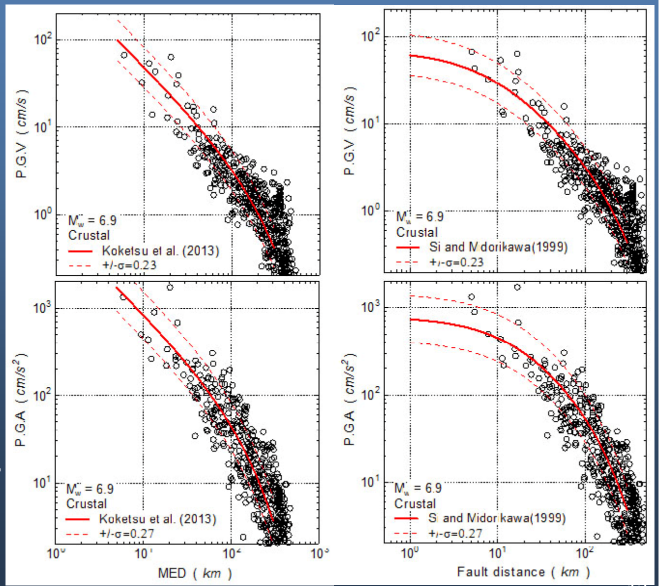
2007 Chuetsu-oki earthquake

- The comparative analysis for the 2007 Chuetsu-oki earthquake not only confirms the validity of the GMPEs derived in this study, but also that the hanging wall effect is resolved to some extent compared to the results of the equations of Si and Midorikawa (1999) using fault distances.



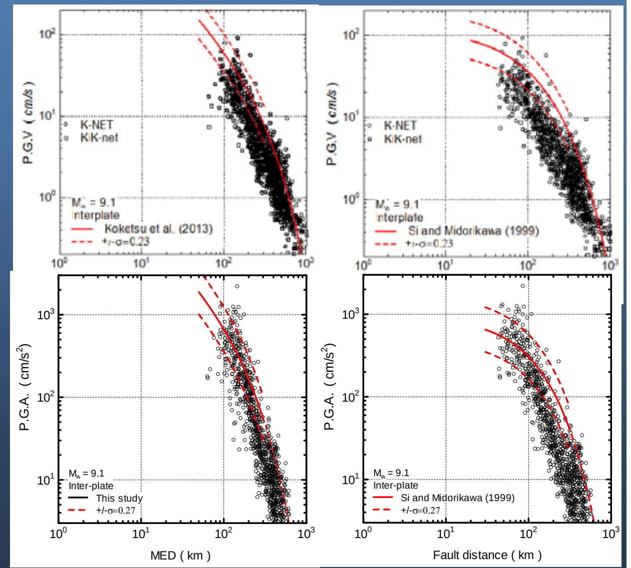
2008 Iwate-Miyagi Nairiku earthquake

- The comparative analysis for the 2008 Iwate-Miyagi earthquake not only confirms the validity of the GMPEs derived in this study, but also that the hanging wall effect is resolved to some extent compared to the results of the equations of Si and Midorikawa (1999) using fault distances.



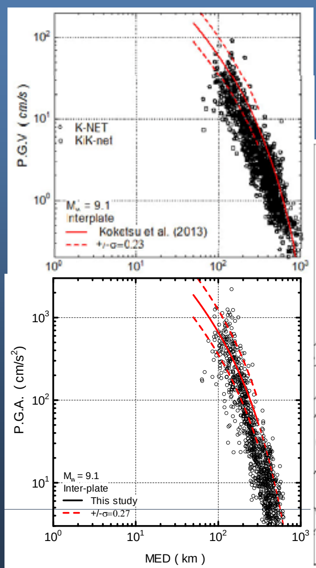
2011 Tohoku earthquake (1)

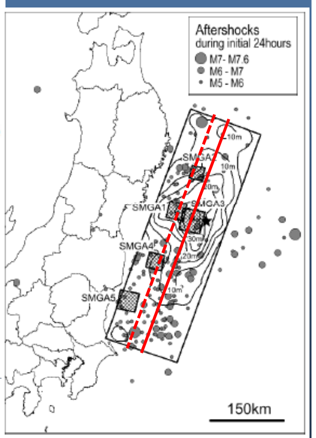
- The comparative analysis for the 2011 Tohoku earthquake confirms the validity of the GMPEs derived in this study.
- On the other hand, as is well known case of the 2011 Tohoku earthquake, the GMPEs using fault distances are overestimating the observed values. This problem of overestimation remains within the GMPEs using median distances even though it is weakened slightly. Therefore, this study suggests that the overestimation is related to not only geometric issues such as the hanging wall effect but also to the source characteristics of megathrust earthquakes.



2011 Tohoku earthquake (2)

- For the 2011 Tohoku earthquake, most of the SMGAs do not coincide with asperities.
- As shown in the right map, the median fault line is a good approximation of the asperity distribution, but not the SMGA distribution.
- If we use the dashed line for measuring median distances, the symbols plotted in the left diagrams will move to shorter distances and the over-estimation will become larger.
- As a result, the effect of the source characteristics of megathrust earthquakes can be larger than expected.





Conclusions

- This study newly defined the term “median distance” and developed new GMPEs by using the dataset of Si and Midorikawa (1999).
- By comparing these GMPEs with the most recent observation data, we found that geometric issues such as the hanging wall effect will be resolved to some extent.
- However, source characteristic issues of megathrust earthquakes still remains.
- The equivalent hypocentral distance and shortest distance from SMGAs also have the characteristics of the median distance but the calculation is made easier with using the median distance.