Dear Referee #1

First of all, authors would like to say thank you very much for your careful review and precious comments to our first manuscript. Authors revised the first manuscript based on the referee #1 and #2. We submitted below files:

1. Revised manuscript with tracking change
2. Revised manuscript without tracking change
3. Letter to referees (this file)

In fact, we submitted texts, figures and tables separately in the first submission. But the revision manuscript has included all in one file in this revision process. Since authors decided to omit some figures based on referee's comment and so we imagined how referee reviewed second manuscript. We thought that it is probably better for both referees to be able to see the figures and tables and recognize which figure was omitted and modified in one file. Hence, the second manuscript includes many revisions and looks complicated. In order to clarify which figures were omitted and how figures were modified to both referees, we left detail revision history. Please accept this approach. Then, we put color maker at the part which referee pointed out in the first review for each referee's comment. We think it is not difficult for referee to find who authors revised in the manuscript. In below, authors put our comment for each referee's comment and we divided some for each revision. In the last, we listed the omitted references and newly added references.
Actually, authors provide two supplement results in this revision. Both referees pointed that the previous manuscript had too many figures so that authors omitted some figures based on the referee's comment. However, authors decided that it might be good to prepare supplement results to explain the contents to both referees. If referee agree with the use of supplement results, we will revise the number of figures in the next manuscript.

Anonymous Referee #1
Received and published: 11 March 2016
In general:

1) Thank you very much for this paper. It match's perfect into the scope of the special issue in Solid Earth. General comments: The paper reports a XCT analysis of pore structure in a natural sand, compare proposed image analysis results with experimental water retention curve and discuss this in respect to REV of pore space. Mostly all details of developed and used methods are described (later follows some remarks and questions) and the application for this case study are demonstrated and discussed. Although the content and nice work presented in this paper, but it needs a major revision. But now looking more into details, first some remarks to the general structure of the presented paper and general questions: The paper overall is a bit "**over-structured"**, some chapters contains short and large sub-chapters with sometimes similar content. Also several different kind of numerations lists (called step 1,2 . . . and other enumerations) hampers fluent

reading and capturing the content. In the Introduction and also in the Discussion chapter, often a lot of literature is only numerate and it is not clear, who is doing what, except the reader knows the cited papers and authors. Better is to rearrange citations and relate directly as reference for the field of research for example (specially p2,l4-6 and p2,l28-p3,l1). Same thing, but here it is better written in p13, l16-33).

Comment to referee #1
Authors revised them for each corresponding part.
Line 3-14 and line 17-21 in page 2
Line 10-14 in page 4 to line 18 in page 4 to line 12 in page 5; and,
Line 8 in page 30 to line 17 in page 31

2) many groups recently working in the field of pore scale imaging, pore morphology approaches and experiments, discussing REVs and a lot of work are published. I missing some recent citations (e.g. Hilfer et al., 2015 for multiphase REVs and length scales or very similar to you a work from Yang et al., Extraction of pore-morphology and capillary pressure curves from porous media from synchrotronbased tomography data, Scientific Reports, 5:10635, DOI: 10.1038/srep10635, 2015, and others . . . The pore-morphology methods are meanwhile highly developed and include drainage and imbibition with different contact angels in complex geometries and realized in software packages (like GeoDict, see geodict.com).

Comment to referee #1
Authors appreciate the precious information about Yang et al. (2015). Their research motivation and approach is similar to ours. We added their work in the introduction on line 5 in page 3.

3) It would be nice to demonstrate more your approach of your combined image processing and pore morphology methods, specially your combination of GIA and VPM looks interesting As we see in many publications, the development of interfacial area between different phases in multiphase flow (experiments and simulations) plays a fundamental rule in this topic. Multiphase flow processes deliver other REVs (and length scales) as “only” single phase or static systems (see Hilfer et al.).

Comments to Referee 1
Authors appreciate the referee’s comment. In fact, authors have started to study the issue which referee pointed out; however, the contents of this paper will be diverse if we include the dynamic issue like multi-phase flow. Hence, we decided not to include that kind of results for this manuscript. However, authors added some comments as future work on line 33 in page 35 to line 3 in page 36.

In future work, it will be necessary to verify the appropriate dimension (i.e. REV) for several kinds of grains with round shape, angular shape and wide range of grain size. These features will provide the issue of pore connectivity with respect to aspect ratio which affects the results of water retention curve.

4) I missing here a discussion. The material: you use Toyoura sand: on p4,l22-23 you give the number of dry density and porosity. What is the mineralogy of the sand? In Fig. 7a you can clearly see, there are different mineral phases. It would be also useful to have a grain size distribution curve (from sieving experiment) and if available some more sedimentological data about this sand (like grain shape analysis which have a lot of impact to pore space geometry) and compare this with your image analysis tools.

Comment to referee #1

Authors performed additional sieving test using different specification from the specification in Japanese geotechnical engineering; actually, we used the specification Japanese concrete engineering so we could add three more plots as shown in Figure 6 (previous number is Figure 9). As for the mineralogy of Toyoura sand, authors added more information in the text and two more references on lines 12 to 14 in page 7.

Toyoura sand has been widely used as benchmark sand for civil engineering in Japan and it is a quartz dominative sand (Miura et al., 1989 and Oluwapelumi et al. 2012).

5) In general: your image analysis implies that the pore structure (grain packing) is not changed over time (e.g. during compaction). You are sure, that in the water retention experiment compaction was not happened? You did only one experiment?

Comment to referee #1

Authors conducted the water retention experiment twice and both samples had same porosity; it was 0.41. This indicates that authors could prepared duplicated sample. We added plot in Figure 13 in page 30

Figures:

6) The paper contains 24 figures! I think this is too much and should be reduced. E.g. figure 1 and figure 5 (illustration of sphere packings) is trivial and not necessary to show, also the figure 3 showing the CT scanner is not necessary. Also better would be a combination of fig. 4 and 14, as the experimental setup.

Comments to referee #1

Authors agreed with referee's comment so we omitted some figures from previous manuscript as follows: Figures 1, 2, 3, 7, 10, 12, 13 and 22 as previous figure number.

Figures 4, 8, 9 and 18 as previous figure number are revised and current figure numbers are Figure 6 in page 21, Figure 4 in page 17, Figure 5 in page 19 and Figure 11 in page 29.

7) The ordering of the figures should have rearranged. Better is to start with an CT reconstructed raw image (like fig. 7) and demonstrate, how the Toyoura sand is composed and represented as a XCT scan.

Comment to referee #1

Authors appreciate the suggestion of referee. Figure 7(a) was omitted; hence, the figure number and related sentence were modified.

8) Fig. 8: it would be better to combine the real porosity/surface each boxel with absolute numbers and RSD in a different axis or as error bars.

Comment to referee #1

Authors appreciate referee's comment and so, we modified Figure 8 (now Figure 4) based on refree's comments. Due to modifying Figure 8, the related sentence is also revised like below in line 25-28 in page 15.

Figure 4(a) and(b) show the analyzed porosity and specific surface area with along with their RSDs for various subsample sizes. In this analysis, the domain size of the subsample size and the location for the initial calculation of the porosity and specific surface were randomly changed 20 times; then, the RSD for each voxel size was calculated. The porosity and specific surface analyzed from the CT images converged owing to the increase in the voxel size; moreover, a tendency to decrease is observed for both parameters. The behavior observed for porosity results in close measured value.

9) Fig. 10: better remove or combine with fig. 9

Comment to referee

Authors appreciate the suggestion of referee. Figure 10 was omitted

10) Fig. 12: same content like fig. 11, but in 3D. Maybe combine or remove.

Comment to referee #1

Authors appreciate the suggestion of referee. Figure 12 was omitted

11) Fig. 13: is that a profile? I think this is a diagram, showing occupied pore space with VPM balls. It would be better to combine and demonstrate the outcome of VPM with Fig. 19.

Comment to referee #1

Authors appreciate the suggestion of referee. We combined Figure 13 with Figure 18 (previous figure number) as Figure 11 in page 22. Due to this modification, some sentence with respect to Figure 11 was added on line 6-13 in page 20

12) Fig. 19: Do you have "only" 5 data points for the experiment, showed in fig. 18? I think you need more measurements between Sr=99% and Sr=28.9%. hp not corresponding to the hp in fig. 18 Fig. 20 shows a strong discrepancy between different boxel sizes and measure points (see remarks to the related chapter)

Comment to referee #1

In this study, water retention test (WRT) had done before image analysis. Even if there are 9 plots obtained from WRT, 5 plots could be compared with Sr obtained from VPM. In fact, it is

difficult to regulate the head between Sr. 99% and 28.9% because small change of capillary head causes large amount of water movement. Hence, we picked up 5 points which measured and analyzed capillary pressure were same or very close.

13) Fig. 21: is unclear to me. What is y-axis?

Comment to referee#1

Authors added more explanation in the text on line 32 in page 31 to line 5 in page 32.

A spherical element is representative of the pore size in this study. The GIA counts the number of voxels for each size of the spherical elements; therefore, we can determine the total number of voxels, which can be multiplied by the volume of one voxel to obtain the total pore volume. Then, it is possible to calculate the percentage of the perforated spherical element for each size of the spherical element on the basis of the volume of the spherical element as the percent finer by volume in Figure 14.

14) Fig. 22: please remove. It can contribute in the text; content to REV and discussions

We agree with referee's comment so we omitted Figure 22; hence the related sentence was also deleted on line 6 to 9 in page 32.

15) Fig. 23: shows a discrepancy between AIM and VPM. This, I think needs more clear discussion in respect to a measured pore size distribution Fig. 24 also shows a clear a strong discrepancy between GMI and VPM (needs discussion)

Comments to referee #1

The concept of AIM models a complicated pore network to pipes. Also, air goes into larger pore space than smaller pore space because of capillary effect. This indicates that the accuracy of AIM for finer pore size should be lower than greater pore size. On the other hand, VPM can scan the pore size using sphere element directly so the accuracy of finer pore size should be better than AIM. Hence, Figure 23 (currently Figure 15) presents large discrepancy between AIM results and VPM results less than 0.06mm. Authors added more discussion on line 12-18 in page 32.

The AIM by Uno et al. (1998) supposes that the pore space in sand exists in a tubular form. Since air wants to intrude a large pore space, it is thought that the evaluation of the pore size by the AIM has a high precision; however, the precision decreases for the evaluation of pore space with a small size, where air does not smoothly intrude. On the other hand, the VPM can easily evaluate the size of a complicated pore space regardless of the physical interaction and does not assume that the complicated pore is a straight tube.

Text (please also see general remarks for structuring the paper and rearrangement of figures):

16) P1, L27: I think you mean Young-Laplace law

Comments to referee #1

Authors revised it on line 28 in page 1.

17) . . .. P2, L20: what means “pore dimensions”?

Authors revised it as pore size on line 30 in page2 and line 1 in page 3.

18) P2, L23: MIT: I know it as MIP (mercuryintrusion porosimetry)

Comments to referee #1

Authors revised it on line 6 in page4.

19) P3, L6-9: this is a bit unclear in the text. Please give an information why it is still under discussion. I think I know what you mean, but it needs to address more or delete this passage.

Comments to referee #1

Authors omitted the sentence at the corresponding location, and move that sentence to on line 26 in page8 to line 3 in page 9.

20) P3, L11-12: often the language and formulationsare not perfect, here repeating’s like “this paper . . .” P3, L23: “this material has a uniform grain shape.” That’s NOT true! If you looking your images, there are different grain shapes!

Comments to referee #1

Authors omitted the sentence at the corresponding location, and explained Toyoura sand a bit more on line 14-16 in page 7

The range of grain sizes is 75–850 μm, and the uniform coefficient, which defined as D_{60}/D_{10}, is 1.5; hence, Toyoura sand is categorized as a classified soil with low range of grain sizes.

21) P4, L1-L13: can be shorter, because it is standard . . .

Authors agree with referee’s comment so the below sentence were deleted on line 1 to 5 in page 6.

In general, 360-degree radioscopic image data, for an inspection object placed on a sample table, is obtained using an X-ray image intensifier by turning the table while irradiating the object with X-rays. This radioscopic image data is then used in reconstruction calculations, which result in cross-sectional images.

The scan speed depends on the scanning conditions. The sample was placed on the scan table and scanned with the cone-shaped X-ray beam.

And also, Figure 3 and its related sentence were omitted on line 10 to 11 in page 6.

Figure 3 shows an illustration of the internal view of the micro-focused X-ray CT scanner.

22) P4, L26-27: do you use special ROI (region of interest) reconstruction method?

Authors do not use special ROI. We added more explanation on line 3-4 in page 8.

In this study, the authors did not use ant special region of interest (ROI) and only used ImageJ to extract the cubic area of interest from the center of the image.

23) P6, L2: why only use 13 sphere elements? Is this the largest sphere radius?

Authors agree with referee's comment so we added more explanation in line 8-12 in page 10.

At the beginning of the granulometric image analysis (GIA) process, the maximum size of a spherical element is not known; therefore, only the appropriate number of radii of the spherical element is given. The GIA analysis continues that the radius of the spherical element is increased until there are no pores that fit that element.

24) P7, L25: what are the real effect of rotation? If this used directly in the further image processing? As I understood, you use later only spheres (see L31)

The comments to referee 1

The meaning of rotating square to diamond shape indicates that the area of square is same as that of diamond. In short, Figure 2 (d) and (e) check the accuracy of GIA even if the shape of pore space is changed, GIA give the same result. Authors revise this sentence on line 10-12 in page 13. Actually, authors used three different abbreviation despite of same meaning. We are sorry. They all should be GIA (granulometric image analysis). We added below message at the corresponding location.

On line 10-12 in page 13

The results in Figures 2 (d) and (e) indicate that the GIA provide the same results, even though the shape of the pore space changed; hence, the GIA can scan the complex pore structure to investigate the pore size.

25) P8, L21: as an idea: you can use cylindrical coordinates, so you are not limited to 700**3 voxels to determine REV. With cyl. oordinates you can use the full field of view of the scanned cylinder. For REV analyses, see my general remarks before.

Authors appreciate referee's suggestion. However, all results described in the manuscript already obtained from square region and it is not so easy to revise all results in cylindrical coordinate. We would like to ask referee to accept this excuse and we will use cylindrical coordinate for next study.

Omitted reference list

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Newly added reference list

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