Int. J. of GEOMATE, Sept., 2015, Vol. 9, No. 1 (Sl. No. 17), pp. 1342-1347
Geotech., Const. Mat. and Env., ISSN:2186-2982(P), 2186-2990(O), Japan

DISTRIBUTION OF LANDFILL BY GEOPHYSICAL EXPLORATION METHODS AT ILLEGAL INDUSTRIAL WASTES DISPOSAL SITE

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ABSTRACT: Serious environmental pollution has caused by illegal disposal of industrial wastes in Kagawa Teshima Island, Kagawa Prefecture, Japan. For restitution of Teshima, a distribution of the industrial waste by the drilling survey by past administration's research became clear roughly. But since the wastes was buried partially such as a pot into the sandy soil layer under the waste layer, it is necessary to investigate in detail the thickness of the wastes as removal of the waste layer progressed.

In this paper, the surface wave prospecting, the microtremor, the Electromagnetic method (EM) sounding and the Continuous wave radar sounding, which is new geophysical exploration methods, were carried out at the illegal industrial wastes disposal site for the purpose of estimating the thickness of the waste layer with sufficient accuracy.

Keywords: Landfill, Investigation, Geophysical Exploration, Surface Wave Prospecting

1. INTRODUCTION

In order to estimate a volume of industrial wastes disposed illegally, it is necessary to measure a ground surface and to investigate a depth of the wastes by boring survey in general. The usual boring survey which uses water at the time of drilling has a possibility of making a contaminant expanding from a waste layer with concern of soil pollution. Because metal and rubber pieces may mix so much in wastes containing shredder dust (SD), it is very difficult to check the depth of wastes such a cone penetration test [1]. And more, the waste may be partially buried deeply such as pot at an illegal disposal. Therefore application of geophysical exploration method which can detect continuous layer thickness distribution is desired strongly.

In this study, some geophysical exploration methods such as the surface wave prospecting and radar exploration were carried out at the illegal industrial waste disposal site, and the detection capability of continuous distribution of the waste layer was discussed.

2. TESHIMA ILLIGAL DISPOSAL SITE

2.1 Topography and Geology

Figure 1 shows the plane of Teshima illegal disposal site. The site is at the seashore part of the northwest of Teshima Island, Kagawa Prefecture. As for the geology of the site, a granite rock, an alluvium soil, a reclamation soil, a banking soil and the wastes are distributed from the lower part. The granite rock has many cracks, and the surface of granite has been weathered strongly [2].

2.2 Amount of Treatment of Wastes

The industrial waste which reaches to about 675,000 tons will carry out from Teshima by March, 2016, and the carry out waste will be processed with incineration and melting style in the disposing facility in Naoshima island next to Teshima by the mediation provision of the pollution mediation with Kagawa Prefecture and Teshima residents [3] [4].

Table 1 shows the amount of treatment of wastes and a polluted soil under wastes by estimating in as of March, 2011. The weight of wastes is increasing from 675 000 at the beginning to 938 000 tons because of an increasing of the waste density and a detection newly of wastes in banking layer soil under wastes layer. The polluted soil under the wastes layer will utilize as a cement material.

Table 1 Amount of treatment

Kind	Volume (Thousands m^3)	Weight (Thousands tons)
Wastes	458.20	499.44
Polluted soil	70.20	122.85
Cover soil	19.40	33.92
Total	547.80	656.21

3. EXPLORATION METHODS

3.1 Survey Line of Investigation

Figure 1 shows the plane with survey lines of three types of geophysical explorations at the site.

The A-A' line was set on the sandy layer after the waste layer was removed, and the surface wave prospecting was carried out only at A-A' line. The B-B' line was set on shredder dust (SD) waste layer, and surface wave prospecting and microtremor were carried out at B-B' line. In addition, there is about 5 m difference in the ground level of A-A' line and B-B' line (see in Photo 1 (a),(b),(c)).

C-C' line and D-D' line of the direction from east to west the surface wave prospecting, the electromagnetic method (EM) sounding, and continuous wave radar sounding were carried out after excavating SD wastes accumulated on the south at B-B' line (see in Photo 2 (a),(b),(c))

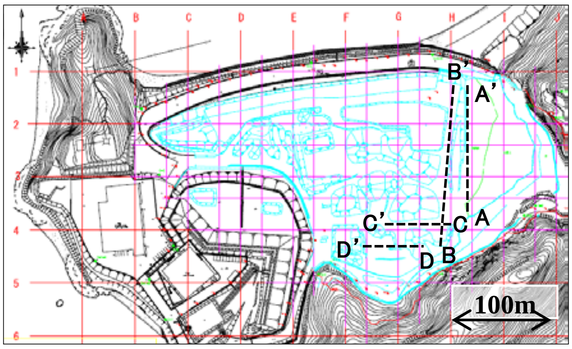


Fig.1 Plane with survey lines of three types of geophysical explorations

Photo. 3 Close view of SD wastes

Photo. 3 shows the close view of the SD wastes. It can see that a large piece of rubber or metal is contained in much quantity.

3.2 Investigation methods

Surface wave prospecting

The Surface wave prospection was carried out by using the high precision surface wave exploration equipment (McSEIS-SXW), and the land streamer type which draws on the surface of the waste layer was used because of roughness of the waste layer. The interval was 0.5 m for vibration points by hummer, and was 1.0 m for receiving points by 24 seismograph sensors. In order to make a seismograph catch certainly vibration transmitted in SD wastes deposited very loosely, it took care so that the base plate of the seismograph sensor might stick to waste.

(a) A-A' line and B-B' line (b) Surface wave prospecting on A-A' line (c) Surface wave prospecting on B-B' line

Photo. 1 State of exploration on A-A' line and B-B' line

(a) C-C' line and D-D' line (b) EM sounding on C-C' line (c) Continuous wave radar sounding on B-B' line

Photo. 2 State of exploration on C-C' line and D-D' line

Microtremor

Measurement of microtremor was used the servo type accelerometer (McSEIS-MT NEO). Microtremor was measured every 10 m at a total of 15 places from the starting point of the B-B' line which carried out surface wave investigation. Because the surface level of the waste layer from 20 m to 70m at the B-B' line was downed by about 1 m from the level at the time of the surface wave investigation by progress of construction, the 1 m was considered when it analyze microtremor date.

Electromagnetic method (EM) sounding

EM sounding is the method of analyzing the conductivity of the ground by observing the artificial induction electromagnetic field which occurs by the current sent through the coil or the loop. EM sounding was used together both measurements of type of EM31 and EM34. It becomes possible to obtain the image sectional view showing a ground conductivity structure by this combined use.

EM31 is a rigid boom type which fixed the transmitting coil and the receiver coil at a certain interval. EM31 is designed to measure by one person only, and is possible to investigate up to 6 m under surface at several hundred points per one day.

EM34 is the measuring device which separates the transmitting coil and the receiver coil. EM34 can be investigated up to about maximum 30m below by changing the distance of the coil separation.

Continuous wave radar sounding

As for method of continuous wave radar sounding, it irradiates electromagnetic waves to ground surface, analyzes the reflected wave from some layers having different electric physical properties (conductivity etc.), and obtains the visible continued image. In order to obtain the analyzed reflective section image (time section image) under the line, the profile method was used in this study. In measurement by the profile method, using a transmitting antenna and a receiving antenna as a pair, it measured by keeping an antenna interval at 3 m and moving a transceiver antenna every 0.5 m. The analyzed reflective section image (time section image) under the line is obtained by putting receiving records of measurement points in order.

4. INVESTIGATION RESULTS

4.1 Distribution of waste layer by surface wave prospecting and microtremor results

Figure 2 shows the analysis result of S-wave velocity V_s obtained by surface wave prospecting on the A-A' line on the sandy layer after the waste layer was removed. Since the V_s indicates 300 m/s over from 0 to 10 m in distance, it seems that the base rock (granite) layer is distributed near this. And it can be said that the high density sandy soil showing about 100 to 300 m/s of V_s is distributed from near 10 m of distance. In addition, at near 90 m of distance, because of influence of the noise by vibration of the exhaust hose crossing at this point was not able to be removed enough, it was considered as the white zone in this figure.

Figure 3 shows the relation between N_s by converting from V_s and N_d by converting from the penetration resistance value by the simple dynamic penetration test at 30 m in Fig. 5(a) and 80m in Fig. 5(b) on A-A' line. N_s is becoming large gradually to the depth estimated to be sandy soil which shows N_s =30 over at 30 m and at 80 m in both figures. And since N_d shows the properties of the sandy soil which is a matrix on the whole although N_d changes largely because a rod hits stones, it can be recognized that N_d is smaller a little than N_s. Here although the simple dynamic penetration test was carried out a total of 17 on A-A' line, it was almost the case that the test was not fully able to carry out because the rod hit frequency a gravel or a cobble stone in the surface layer.

Figure 4 shows the S-wave velocity V_s and the point of microtremor on B-B' line which is on the waste. V_s indicates about 300 m/s because of the base rock (granite) at near the starting point. And it can be clear that the waste layer that is V_s < 100 m/s distributed from 15 m to the end of distance. The thickness of the waste layer can be estimated to be around 5 m judging from the value of V_s. Since the difference of the surface level between B-B' line which is on the waste and A-A' line which is in the sandy soil is about 5 m from the

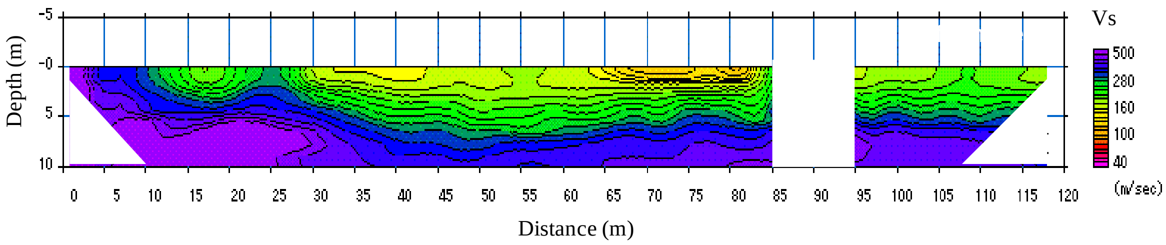
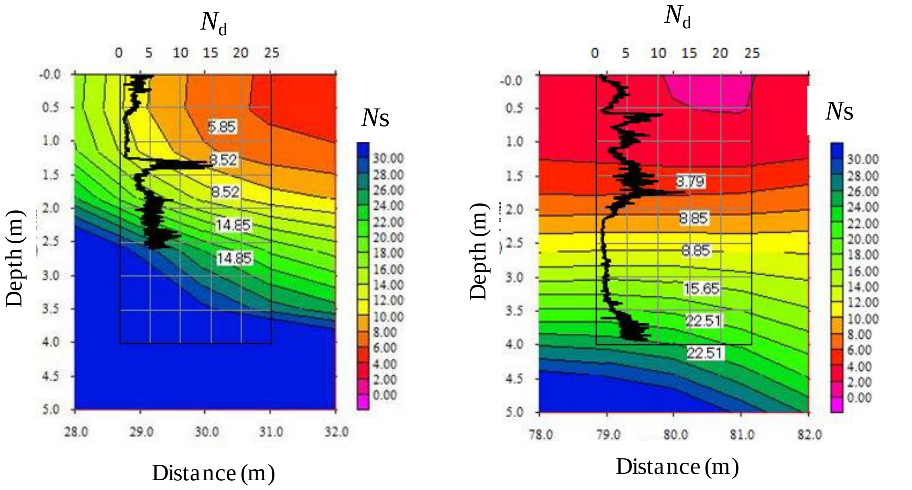


Fig.2 Analysis result of S-wave velocity Vs obtained by surface wave prospecting on the A-A' line



(a) Point at 30 m on A-A' line (b) Point at 80 m on A-A' line

Fig.3 Relation between N_s from V_s and N_d from the penetration resistance value

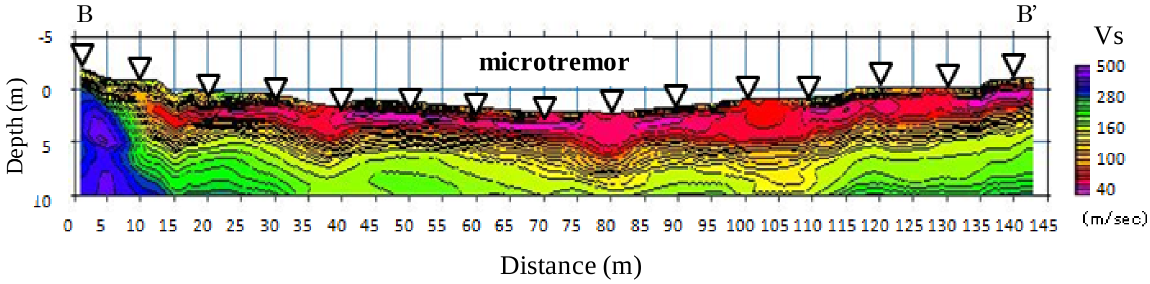
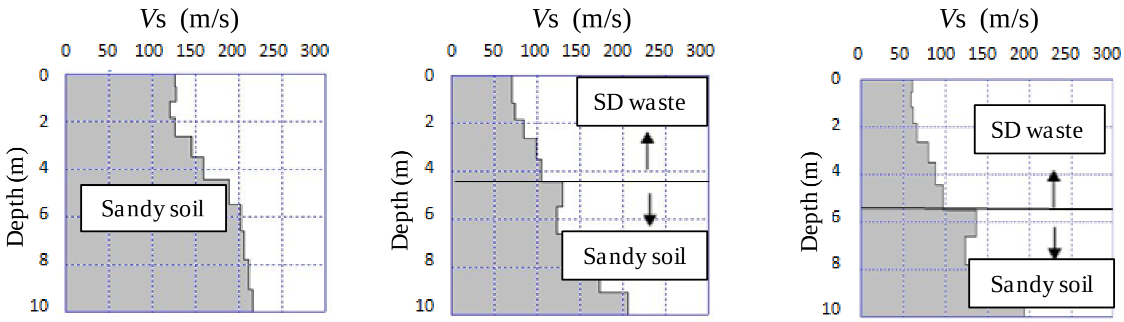
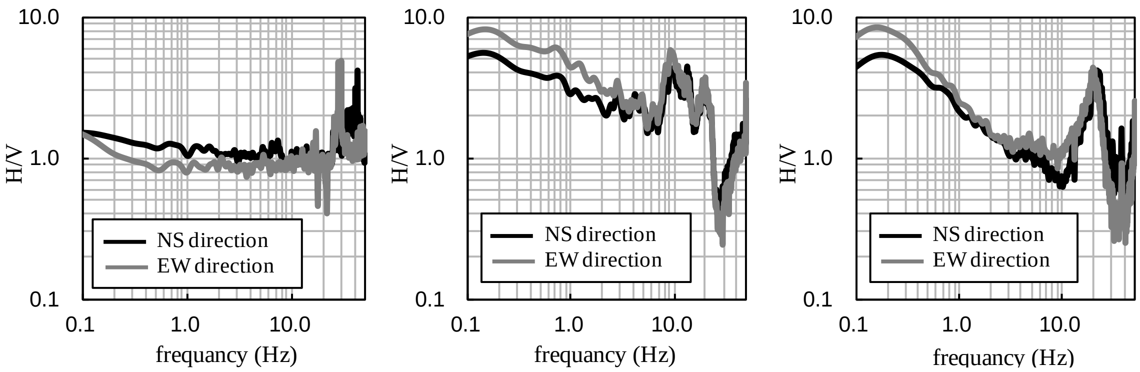


Fig.4 S-wave velocity V_s and the point of microtremor on B-B' line



(a) Point at 10 m (b) Point at 30 m (c) Point at 80 m

Fig.5 Change of Vs toward depth at each point on B-B' line



(a) Point at 10 m (b) Point at 30 m (c) Point at 80 m

Fig. 6 H/V spectral ratio on B-B' line

point of direct survey, it can be confirmed that the thickness of the waste layer is about 5 m on B-B' line. Moreover, although the contour line of S-wave velocity shows a shape as a concave at 40 m, 80 m and near 105 m in distance, it suggests that a existence of undiscovered wastes into the sandy soil under the waste.

Figure 5 (a), (b) and (c) show the in-depth profile of V_s at 10m, 30 m and 80 m in distance individually. The waste does not accumulate at the point of 10 m in distance, and the V_s of sandy soil indicates more than about 120 m/s in Fig. 5(a). On the other hand, the waste accumulated at 30 m in Fig. 5(b) and at 80 m in Fig.5(c), it estimated that the value of S-wave velocity of the waste layer is V_s < 110 m/s.

Figure 6 (a), (b) and (c) show the H/V spectral ratio obtained by analyzing a ground micro vibration by the microtremor at the same point as above Fig. 5. Frequency of 10 Hz or more was judged to be the frequency corresponding to the base rock. And since the site was near the seashore, the frequency of 1.0 Hz or less was judged to be the value having an influence of sea wave. Therefore the frequency which shows the value of a high H/V spectrum in the range with a frequency of 1.0 to 10 Hz was judged to be the frequency corresponding to the waste layer.

Now, the thickness of the waste layer can be calculated by the 1/4-wave rule shown in equation (1) using the frequency f corresponding to *Vs* of the waste layer and waste layer of an every place point.

$$H = V_s / 4f \qquad \text{eq.(1)}$$

Here, H : estimated thickness of waste layer (m).
f : frequency corresponding to waste layer obtained by the microtremor (Hz).
V_s : S-wave velocity obtained by Surface wave prospecting (m/s).

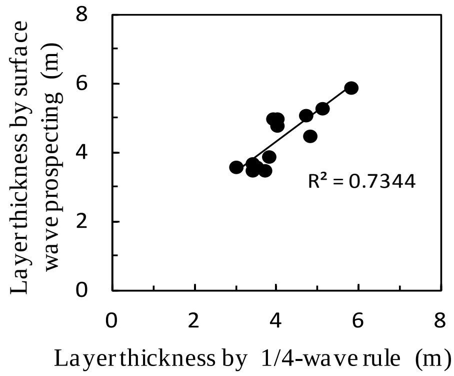
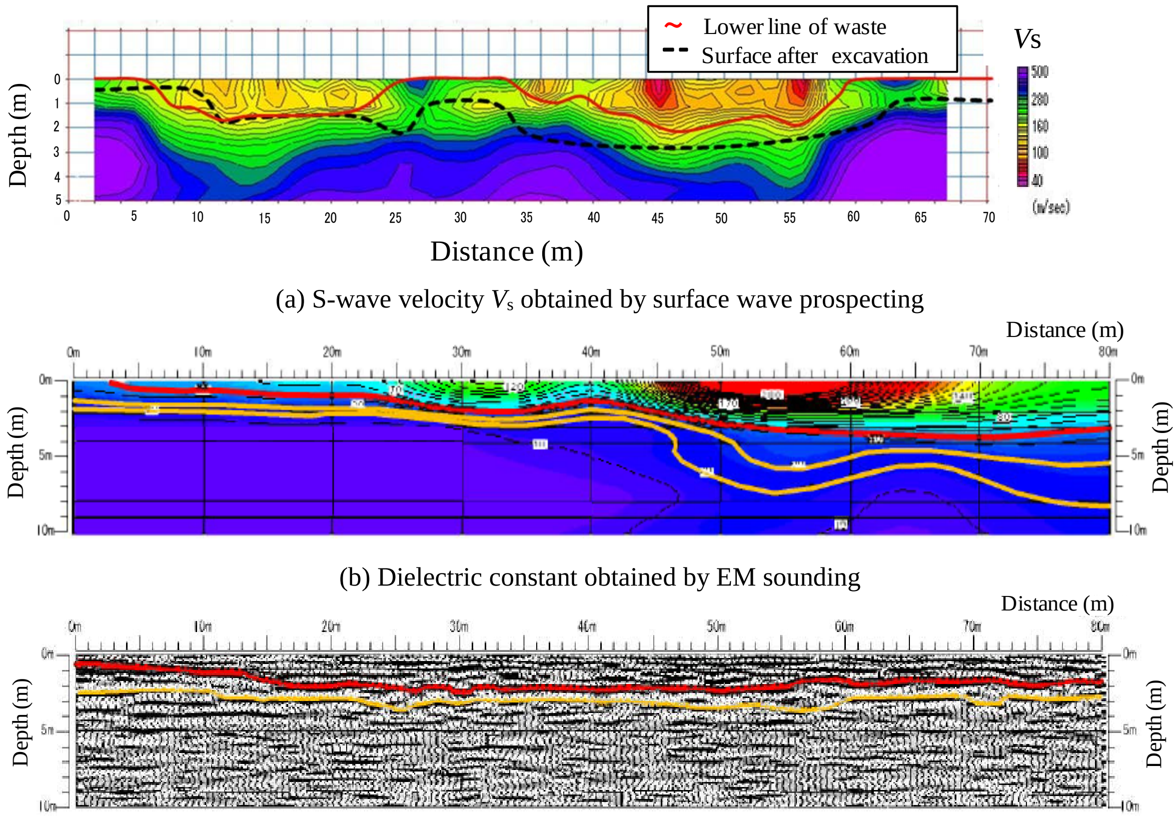


Fig.7 Correlation of layer thickness by surface wave prospecting and one by 1/4-wave rule



(a) S-wave velocity V_s obtained by surface wave prospecting

(b) Dielectric constant obtained by EM sounding

(c) Reflected wave obtained by continuous wave radar sounding

Fig.8 Results of geophysical exploration methods on C-C' line

Figure 7 shows the correlation of layer thickness by surface wave prospecting and one by 1/4-wave rule. It became clear that both layer thicknesses had positive correlation, and it can be said that the thickness of the waste layer by two geophysical investigation methods has enough accuracy.

4.2 Distribution of layer thickness by EM sounding and continuous wave radar sounding

Figure 8 (a), (b), (c) show the decipherment result by three kinds of geophysical exploration carried out on the SD waste on C-C' line individually. From Fig. 8 (a) which is result of the surface wave prospecting, the layer of the value of V_s=80~120 m/s distributes in the surface on C-C' line, therefore this layer is estimated to be the SD waste layer. The red line in the figure means the boundary between the SD waste layer and the sandy soil layer. Since the red line falls largely at 8~25 m and 35~60 m in distance, it is considered that the waste is buried such as a pot. After the removal work of the SD waste was carried out after of proceeding the surface wave prospecting on C-C' line. The dashed black line shows the surface of sandy soil after the removal work. Although the lower boundary of the estimated waste layer correspond mostly to the surface of sandy soil at 10~20 m in distance, the surface of sandy soil seems to be deeper about 1~2 m in depth at other area. As this reason, it considered that the sandy soil mixed wastes a little under the SD waste and a discolored sandy soil which anxious about contamination was removed together. And more, although the value of V_s of the estimated SD waste on C-C' line is bigger a little than the one of the SD waste on A-A' line, it can be said that it is influence of increase of density of the SD waste in order to mix much sandy soils into the SD waste on C-C' line.

From Fig. 8(b) which is result of the EM sounding, the contrast of comparatively clear conductivity is detectable. The dielectric constant of the waste layer is 50 or more mS/m, and one of the base rock (granite) set as 20 or 30 mS/m each. Although there is a zone where a dielectric constant shows 150 mS/m or more at 45 ~ 70 m in distance, it can guess that the waste of different density is buried in this zone. And from Fig.8(c) which is result of the continuous wave radar sounding, the reflected wave of two lines was detected comparatively clearly. The above line was estimated as the reflected wave of undersurface boundary of the waste, and the low line was estimated as the reflected wave of upper surface boundary of the granite. On the other hands, as for the thickness of sandy soil layer, it can be read as 3 ~ 4 m by the surface wave prospecting, as 1 ~ 3 m by the EM sounding, and as 1 ~ 2 m by the continuous wave radar sounding.

5. CONCLUSIONS

As a result of this study, important conclusions are summarized as follows.

1) The S-wave velocity of the SD waste of Teshima Industrial illegal disposal site is very low, it estimates about *V*s= 100 m/s.
2) With the combination of the surface wave prospecting and the microtremor, it can estimate useful accuracy the thickness of the waste layer.
3) The surface wave prospecting is most suitable for estimation of the thickness of the SD waste layer among three kinds of geophysical exploration methods by this study.

6. ACKNOWLEDGEMENTS

The authors would like to appreciate Mr. Masaya Komino of the waste management division, Kagawa prefectural office for his support in carrying out this study, Miss. Takako Takahashi of OYO Corporation for her technical advice for the surface wave prospecting, and Mr. Kiyoshi Yoshida of Kawasaki Geotechnical Engineering Co.,Ltd. for his technical advice for the EM sounding and the continuous wave radar sounding.

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Int. J. of GEOMATE, Sept., 2015, Vol. 9, No. 1 (Sl. No. 17), pp. 1342-1347.

MS No. 4306 received on Dec. 23, 2014 and reviewed under GEOMATE publication policies.

Pertinent discussion including authors’ closure, if any, will be published in Sept. 2016 if the discussion is received by March 2016.

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