# Study on non-uniformity coefficient of grounds for examining seismic performance of water pipes in consideration of microtopography classifications and boundary conditions

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**Abstract** High damage ratios of embedded pipes are seen in microtopography boundaries in a microtopography classification map. Moreover, the past studies have revealed that ground with high non-uniformity is vulnerable to earthquakes. Therefore, it has become necessary to examine earthquake-resistant performance of embedded pipes for which non-uniformity (area where ground constitutions and hardness and softness vary) of ground is considered. The non-uniformity coefficient is defined in "the seismic methods 2009 edition guideline description waterworks". For this non-uniformity coefficient, the authors calculated ground strain by static and dynamic analyses based on types and boundary conditions of microtopography using data of water pipes damaged by the 2004 Niigataken Chuetsu earthquake and the 2007 Niigataken Chuetsu offing earthquake, a microtopography classification map and ground data. Their results were compared and the non-uniformity coefficient for which types and boundary conditions of microtopography were considered was examined.

**Keywords.** (earthquake-resistant，water pipline，non-uniformity coefficient，microtopography classification map，mictotopography boundary)

## 1. Introduction

The Great East Japan Earthquake in March 11, 2011 brought unprecedented damage to roads, water supply, sewerage system, electricity, gas and so on. Among lifeline facilities, the water supply was suspended by destruction of pipelines for about 2,200,000 houses mainly in Miyagi prefecture[1], indicating that great damage was brought extensively. As of 2010, the diffusion rate of water supply is 97.5%[2] and influences of sudden suspension of water supply and reduction of water are unmeasurable.

Therefore, securing earthquake-resistant for water supply facilities is essential for various activities such as operation of domestic water, fire fighting water or hospitals and it is necessary for the pipes that are going to be newly installed in the future to have quake resistance. Further, it is needed to determine precedence to enhance the quake resistance for those presently embedded and modify them.

On the other hand, the water pipe damage ratio in Sendai-city by the Great East Japan Earthquake in 2011 is 0.07 locations /km and is smaller than 0.32 locations /km, which is of Kobe-city by Hyogoken-nanbu earthquake in 1995[1]. The fact that ground deformation in the bad ground was restrictive is one of the factors and non-uniformity of artificially modified parts and grounds where ground deformation easily occurs damages embedded pipes such as waterlines. Studies on embedded pipes or past seismic damage have revealed that pipeline damage is concentrated in the areas where non-uniformity of the ground (area where ground constitutions and hardness and softness vary) is high. Moreover, since it has come to be understood that pipeline damage ratio is high in microtopography sections in boundaries in the microtopography classification map, it is important to examine earthquake-resistant performance of the embedded pipe for which non-uniformity of ground is considered.

Design method in the non-uniform ground is shown in "the seismic methods 2009 edition guideline description waterworks"[2] (hereinafter referred to as seismic water facilities method guidelines). The design method calculates displacement by a dynamic analysis as a general rule. However, for underground pipelines, which widely form network in the plane, designs for which non-uniformity coefficient is considered are presently emphasized in terms of time and cost for static analyses by comparatively easy response displacement methods. The non-uniformity coefficients shown in seismic water facilities method guidelines were determined by a study[3] of Nishio, who examined gas pipes' damage caused by 1978 Miyagiken-oki earthquake and set as shown in Table 1. The coefficient shown in the seismic water facilities method guidelines is classified into only three categories, and a result may be wrong depending on the choice of the coefficient by the designer. Therefore, using the pipeline damage by the 2004 Niigataken Chuetsu earthquake and the 2007 Niigataken Chuetsu offing earthquake and the microtopography classification map that a designer can easily obtain, we examined non-uniformity of the ground focusing on pipeline damage concentrated on the microtopography boundaries[3]. As shown in Table 2, microtopography sections are summarized to "good ground" and "bad ground" similar to the presence of the earthquake-resistant compatibility described in "the earthquake-resistant compatibility ground judgment support handbook of the ductile cast iron pipe K-type joint" [5]. As a result of studying the damage ratio by the method similar to Nishio's[3], calculation of non-uniformity coefficient based on physical quantities other than microtopography boundaries of the good ground has revealed that non-uniformity rises most in a microtopography boundary part of the good ground[3]. In the microtopography boundary part, ground constitutions often become non-uniform, and dynamic properties of the ground such as proper period also change, the authors presume.

Therefore, in this study, considering types of microtopography sections and microtopography boundary conditions, ground strain are calculated by the static analysis and the dynamic analysis and are compared. Based on the result, the non-uniformity coefficient is examined based on types of microtopography sections and microtopography boundary conditions.

Table.1 Non-uniformity coefficient[4]

| Degree of non-uniformity | Non-uniformity coefficient | Ground conditions |
|---|---|---|
| Uniformity | 1.0 | Diluvial ground, Uniform alluvial ground |
| Nonuniformity | 1.4 | Alluvial ground thickness varies somewhat severe, Ordinary residential hills |
| Extremely nonuniformity | 2.0 | River basin, Very uneven ground, such as alluvial drowned valley<br>Developed land for a large cut and earth embankment |

Table.2 Classification of microtopography
（Added to "Seismic compliance decision support handbook ground ductile iron pipe with K-type joints etc"[5]）

| No | Microtopography | Decision | Division Study |
|---|---|---|---|
| 1 | Mountains | Seismic compliance have | Good ground |
| 2 | Piedmont areas | | |
| 3 | Hill | | |
| 4 | Volcanic areas | | |
| 5 | Volcanic piedmont areas | | |
| 6 | Volcanic hills | | |
| 7 | Mesa | | |
| 8 | Quality gravel plateau | | |
| 9 | Rohm plateau | | |
| 10 | Lowland valley | No seismic compliance | Bad ground |
| 11 | Alluvial fan | | |
| 12 | Natural levee | | |
| 13 | Backswamp | | |
| 14 | Old River Road | | |
| 15 | Delta· Coastal lowland | | |
| 16 | Reef· In gravel | | |
| 17 | Dune | | |
| 18 | Reef· Between the lowland dunes | | |
| 19 | Reclaimed land | | |
| 20 | Reclaimed land | | |
| 21 | Rocky· reef | | |
| 22 | Riverside | | |
| 23 | River channel | | |
| 24 | Lake | | |

## 2．Non-uniformity coefficient

*2-1 Non-uniformity coefficient*

Earthquake-resistant design calculations for pipelines are described in the seismic water facilities method guidelines and non-uniformity coefficient is used for obtaining reference ground strain of the pipe's axial direction. Although it is presumed that earthquake waves propagate on the uniform ground (ground without stratum change in the horizontal direction) for the reference ground strain, there actually exist almost no uniform grounds but non-uniform grounds in which stratums change. In such a case, it is necessary to perform a high analysis by a dynamic analysis to clarify dynamic deformation properties and perform an earthquake-resistant analysis. However, in lifeline facilities such as water supply or sewerage systems, their diameters are comparatively small and their extension is long and therefore it is not reasonable to perform a dynamic analysis in all non-uniform grounds from the viewpoints of cost and time. Therefore, it is needed to consider non-uniformity of the ground in the designed location in a static analysis and compensate the reference ground. Concretely, as seen in Equation (1), reference ground strain is obtained by multiplying the non-uniformity coefficient of ground by the reference ground strain in the pipe's axial direction for considering non-uniformity of the ground. Therefore, comparison between the ground strain in a static analysis and that in a dynamic analysis enables to grasp properties related to the non-uniformity coefficient.

$$\varepsilon_G = \eta \times \frac{\pi U_k}{L} \quad (1)$$

Here,

$\varepsilon_G$ : Reference ground strain (pipe's axial direction)

$\eta$ : Non-uniformity coefficient of the ground

$U_K$ : Horizontal displacement and amplitude (m) of the ground in the pipe axis

$L$ : Wave length (m)

## 3．Examination outline and location for analysis

*3-1 Examination outline*

As a result of studying non-uniformity of the boundaries and the parts other than those in the good ground and the bad ground in the microtopography section based on pipeline damage ratios, it has been revealed that non-uniformity of the ground in the microtopography boundary part of the good ground is high[3)]. Since actual ground strain is estimated by multiplying the non-uniformity coefficient by ground strain obtained by a static analysis, we confirmed differences by types of microtopography and boundary conditions by comparing ground strain obtained by static analysis with that by a dynamic analysis. Here, the subjects were Nagaoka-city and Ojiya-city damaged by the 2004 Niigataken Chuetsu earthquake and Kashiwazaki-city and Kariwamura damaged by the 2007 Niigataken Chuetsu offing earthquake. We built a ground model at the location where ductile cast iron pipes were damaged and performed analyses by a one-dimensional response displacement method and a two-dimensional seismic response analysis by the method same as that described in the seismic water facilities method guidelines.

The analysis locations were extracted in consideration of microtopography sections and pipeline damage locations and Natl. Res. Inst. for Earth Sci. and Disaster Prevention J-SHIS subsurface ground[6)] was used as a microtopography classification map. These data are arranged in the smallest mesh size in the microtopography classification map and are downloadable from the web page. In addition, they have broad utility, evaluation can be done with indices that are uniform nationwide and designers can easily acquire them. Moreover, the pipeline damage data were collected and organized by Japan Water Research Center in "Estimation of pipelines damaged by an earthquake for which priority of facilities update is considered" which was supported by Grant-in-Aid for Scientific Research from MHLW.

*3-2 Analysis location*

Locations where there were damaged pipelines and boring data that enable us to understand base surfaces around were chosen as analysis targets and were extracted based on types of microtopography and boundary conditions. From Nagaoka-city (Figure 1), Ojiya-city (Figure 2), Kashiwazaki-city (Figures 3 and 4) and Kariwamura (Figure 4), three cases were extracted for the good ground and the bad ground for locations where there are pipeline damage in the places other than microtopography boundaries and boundaries as shown in Table 3. Further, boring data were extracted with Hokuriku Ground Information System[7].

Table.3 List of analysis positions

| case | Division Study | Boundary condition | Area name | Microtopography |
|---|---|---|---|---|
| 1-1 | Bad ground | Boundary | Kashiwazaki | Backswamp |
| 1-2 | | | Kariwa | Lowland valley |
| 1-3 | | | Kariwa | Dune |
| 2-1 | Good ground | | Ojiya | Quality gravel plateau |
| 2-2 | | | Nagaoka | Quality gravel plateau |
| 2-3 | | | Kashiwazaki | Quality gravel plateau |
| 3-1 | Bad ground | Outside boundary | Kashiwazaki | Delta・Coastal lowland |
| 3-2 | | | Kashiwazaki | Alluvial fan |
| 3-3 | | | Kariwa | Backswamp |
| 4-1 | Good ground | | Ojiya | Quality gravel plateau |
| 4-2 | | | Ojiya | Quality gravel plateau |
| 4-3 | | | Ojiya | Quality gravel plateau |

Table.4 Analysis data using the response displacement method

| case | Division Study | Boundary condition | Microtopography | Boring date name |
|---|---|---|---|---|
| 1-1 | Bad ground | Boundary | Backswamp | 56380436003 |
| 1-2 | | | Lowland valley | 56381542001 |
| 1-3 | | | Dune | E-h-3 |
| 2-1 | Good ground | | Quality gravel plateau | Y-a-17 |
| 2-2 | | | Quality gravel plateau | V-c-17 |
| 2-3 | | | Quality gravel plateau | Kashiwazaki NO3 |
| 3-1 | Bad ground | Outside boundary | Delta・Coastal lowland | No123+05 |
| 3-2 | | | Alluvial fan | F-H-26 |
| 3-3 | | | Backswamp | D-I-80 |
| 4-1 | Good ground | | Quality gravel plateau | Y-a-6 |
| 4-2 | | | Quality gravel plateau | 55387653001 |
| 4-3 | | | Quality gravel plateau | Y-a-21 |

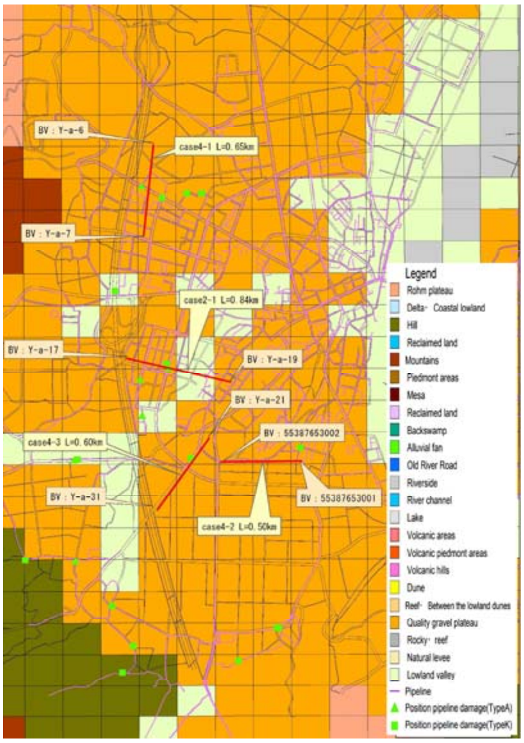


Fig.1 A damage position and analysis position in Ojiya city

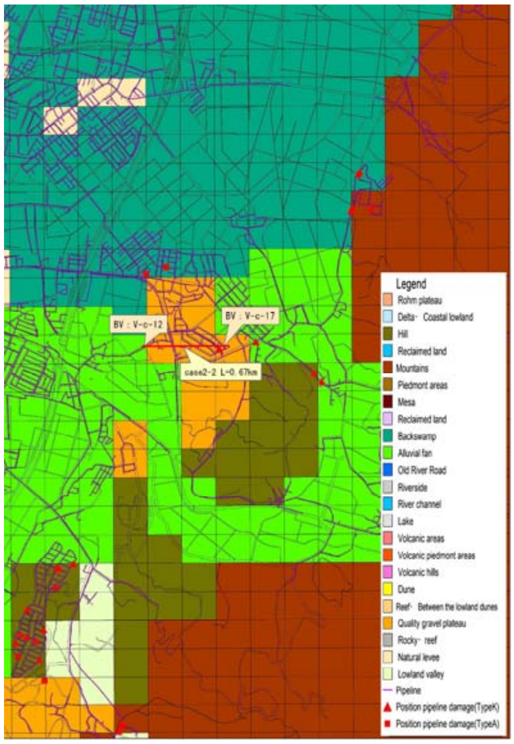


Fig.2 A damage position and analysis position in Nagaoka city

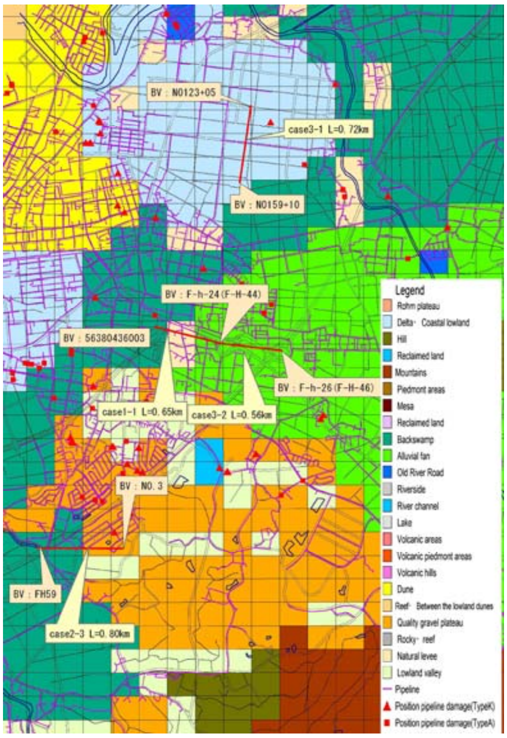

Fig.3 A damage position and analysis position in Kashiwazaki city center

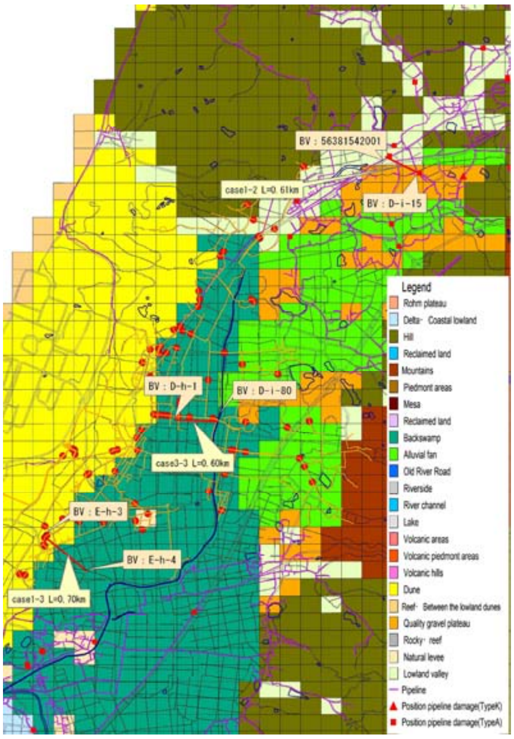

Fig.4 A damage position and analysis position in Northern of Kshiwazaki city and Kariwamura

## 4. Study by static analysis

*4-1 Ground strain by response displacement method*

In the analysis by the response displacement method described in the seismic water facilities method guidelines, ground strain is obtained from displacement of the subsurface ground as expressed by Equation (1). When performing earthquake-resistant check of existing embedded pipes and anti-earthquake design of new embedded pipes by static analyses, reference ground strain is calculated by the response displacement method with boring data from the vicinity of the design location. In this study, reference ground strain is calculated with boring data in the same microtopography section for the vicinity of the pipeline damage location,.

*4-2 Analysis conditions for ground strain estimation by the response displacement method*

(1) An analysis location is to be on a boring location in the vicinity of the pipeline damage in Figures 1-4, categorized in the microtopography section type same as that shown in Table 3, and is as shown in Table 4.
In the case that boundary conditions are outside boundary, boring data from the vicinity of the pipeline damage location with clear base surface were chosen.
(2) Distortional wave velocity Vs was estimated from N value from boring data by the method described in the seismic water facilities method guidelines and proper periods were calculated.
(3) The depth of the pipeline was assumed 1.5m.
(4) The earthquake-resistant calculation method is same as the ground strain estimation method described in the seismic water facilities method guidelines and also the velocity response spectrum described in the guidelines was used for the study.

*4-3 Analysis result*

Table 5 shows results of an analysis of proper periods calculated from boring and reference ground strain obtained by the response displacement method. In actual design work, these values are multiplied by the non-uniformity coefficient to obtain design reference ground strain. As these results indicate, even a microtopography section with the good ground such as CASE4-1 is the Type III ground and ground constitutions and proper periods cannot be specified only by microtopography sections. However, most of others are Type III for the bad ground, and Types I and II for the good ground. Therefore, because the ground is soft and the peculiar period is long, the ground strain in the bad ground is large. In addition, the ground distortion is small because the good ground has a short peculiar period. In addition, the ground strain is small in the results because the good ground has a short peculiar period.

Table.5　Ground strain by the response displacement method

| CASE | Microtopography | | Proper period (s) | Ground classification for the Proper period | Velocity response spectrum of earthquake vibration in the base ground surface (cm/s) | Horizontal displacement amplitude of the ground on the pipe axis (mm) | Wavelength (m) | Ground strain (%) |
|---|---|---|---|---|---|---|---|---|
| 1-1 | Backswamp | Bad ground | 1.056 | Ⅲ | 100 | 213.57 | 210.483 | 0.319 |
| 1-2 | Lowland valley | | 1.032 | Ⅲ | 100 | 208.66 | 200.334 | 0.327 |
| 1-3 | Dune | | 1.688 | Ⅲ | 100 | 341.79 | 332.723 | 0.536 |
| 2-1 | Quality gravel plateau | Good ground | 0.268 | Ⅱ | 28 | 14.72 | 52.557 | 0.088 |
| 2-2 | Quality gravel plateau | | 0.304 | Ⅱ | 32 | 19.25 | 60.809 | 0.099 |
| 2-3 | Quality gravel plateau | | 0.340 | Ⅱ | 45 | 30.37 | 65.881 | 0.157 |
| 3-1 | Delta・Coastal lowland | Bad ground | 1.944 | Ⅲ | 100 | 393.70 | 385.058 | 0.321 |
| 3-2 | Alluvial fan | | 1.500 | Ⅲ | 100 | 303.70 | 310.194 | 0.308 |
| 3-3 | Backswamp | | 1.044 | Ⅲ | 100 | 211.08 | 200.600 | 0.331 |
| 4-1 | Quality gravel plateau | Good ground | 0.836 | Ⅲ | 100 | 168.57 | 141.097 | 0.375 |
| 4-2 | Quality gravel plateau | | 0.176 | Ⅰ | 18 | 5.92 | 33.800 | 0.055 |
| 4-3 | Quality gravel plateau | | 0.092 | Ⅰ | 8 | 1.11 | 18.072 | 0.019 |

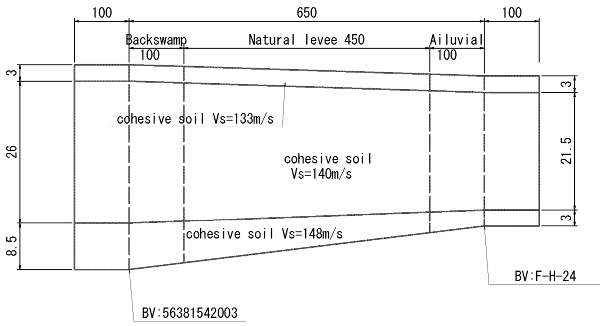


Fig.5　Geological cross section for Case 1-1 (Unit:m)

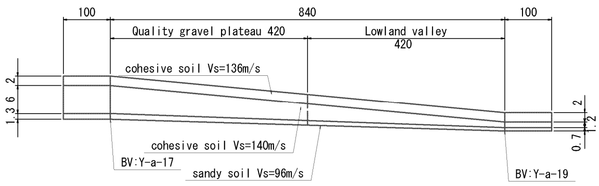


Fig.6　Geological cross section for Case 2-1 (Unit:m)

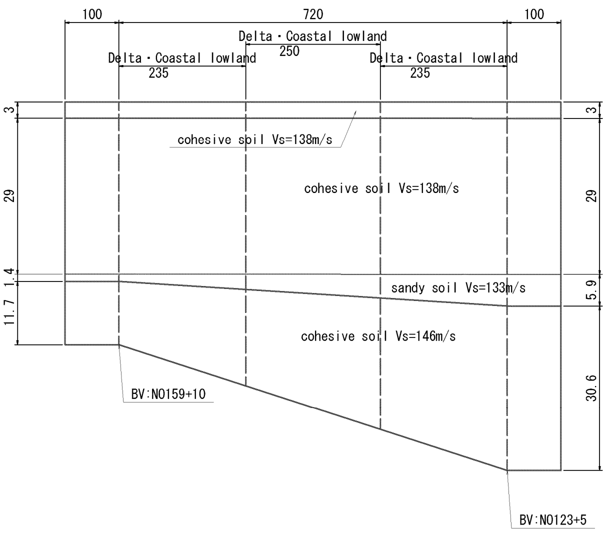


Fig.7　Geological cross section for Case 3-1 (Unit:m)

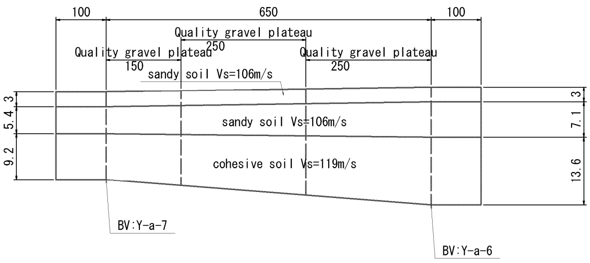


Fig.8　Geological cross section for Case 4-1 (Unit:m)

## 5．Examination by dynamic analysis

*5-1 Analytical model*

On the basis of boundary conditions and types of microtopography, a soil cross section was made by the bowling for the microtopography section that was adjacent at the static analysis calculation position in CASEs1-1 - 4-3 in Figures 1-4 and modeled. In the soil cross section diagram, the soil layer is interpolated with a linear line from boring at two points and variation of stratum between the two points is not taken into consideration.

As a model example, cross section diagrams for CASE1-1, CASE2-1, CASE3-1 and CASE4-1 are shown in Figures 5-8. The altitude of the soil cross section was from boring data and 100m horizontal in the distance between boring was added to both sides of the model so that slanted parts and its neighborhood would not be affected. Unit weight in the physical property was based on the design provision "Road"[8]. The Poisson's ratio was assumed as 0.45. Distortional wave velocity Vs was estimated from N value in accordance with the seismic water facilities method guidelines.

Further, in this model map, the same soil layers are connected with a linear line from the boring data at two points. However, since the ground line would be more complicated in the actual ground, it is thought that the ground strain would be smaller than that in the actual ground.

*5-2 Analysis condition*

(1) Two-dimensional linear FEM was used as an analytical technique.
(2) Direct integration method by Newmark beta method (beta =1/4) was used for the numerical method.
(3) Analysis time was 0.005sec, response analysis time was 30sec and the total step was 6000 steps.
(4) As a boundary condition, the side boundaries were fixed in the vertical direction, its horizontal direction was freed and the base boundary (engineering base surface) was fixed.
(5) Input earthquake motion was Type211 in Road bridge specifications anti-earthquake design[9] (See Figure 9).
(6) Mesh widths were 2m or 3m in the horizontal direction and 1m or 2m in the vertical direction.
(7) SoilPlus[10], which is a general software, was used as an analyzing program.

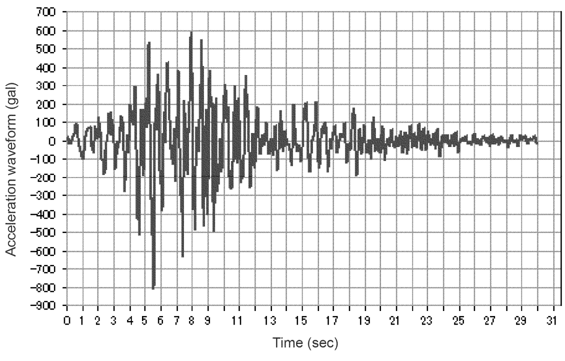


Fig.9 Acceleration waveform

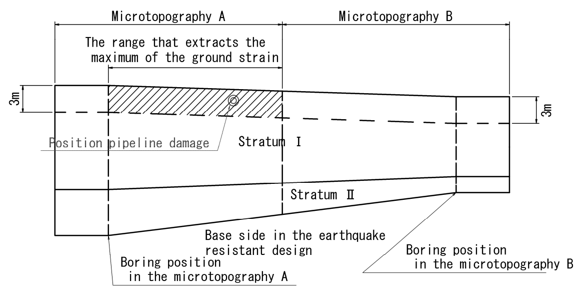


Fig.10 The range that extracts the maximum of the ground strain

*5-3 Analysis result*

We performed a seismic response analysis for twelve grounds and boundary conditions shown in CASE1-1 to CASE4-3 and examined axial strain that affects pipeline. Among axial strain distribution maps, strain distribution maps of CASE1-1, CASE2-1, CASE3-1 and CASE4-1 are shown in Figures 11-14 as an example. The ground strain calculated by the response displacement method, when calculating ground strain for boring in the microtopography section A shown in Figure 10, indicates a representative value of the ground strain in the microtopography section A. In order to compare results of earthquake response analysis with the ground strain obtained by the response displacement method, the maximum value of the ground strain in the microtopography section A was extracted for ground strain obtained by the earthquake response analysis. Moreover, since the buried depth of a pipeline generally is around 3m, the strain was extracted from the point less than 3m deep from the surface. As shown in Table 6, as a result of extracting by the earthquake response analysis the maximum axial strain at the point less than 3m deep from the surface in the microtopography section where the pipeline was damaged, it has been revealed that strain was smaller in the good ground and strain at the spots outside boundaries tended to be smaller. However, such tendency varies depending on the cases and not only the types and boundary conditions of the microtopography but also degrees of the sudden change of the topography and ground affect the ground strain, we presume.

Table.6 Ground strain by the seismic response analysis

| case | Division Study | Boundary condition | Microtopography | The maximum of the ground distortion in the shallower than 3m ground (%) | Average (%) |
|---|---|---|---|---|---|
| 1-1 | Bad ground | Boundary | Backswamp | 0. 360 | 0. 468 |
| 1-2 | | | Lowland valley | 0. 776 | |
| 1-3 | | | Dune | 0. 269 | |
| 2-1 | Good ground | | Quality gravel plateau | 0. 121 | 0. 346 |
| 2-2 | | | Quality gravel plateau | 0. 343 | |
| 2-3 | | | Quality gravel plateau | 0. 574 | |
| 3-1 | Bad ground | Outside boundary | Delta・ Coastal lowland | 0. 473 | 0. 460 |
| 3-2 | | | Alluvial fan | 0. 595 | |
| 3-3 | | | Backswamp | 0. 311 | |
| 4-1 | Good ground | | Quality gravel plateau | 0. 705 | 0. 273 |
| 4-2 | | | Quality gravel plateau | 0. 075 | |
| 4-3 | | | Quality gravel plateau | 0. 038 | |

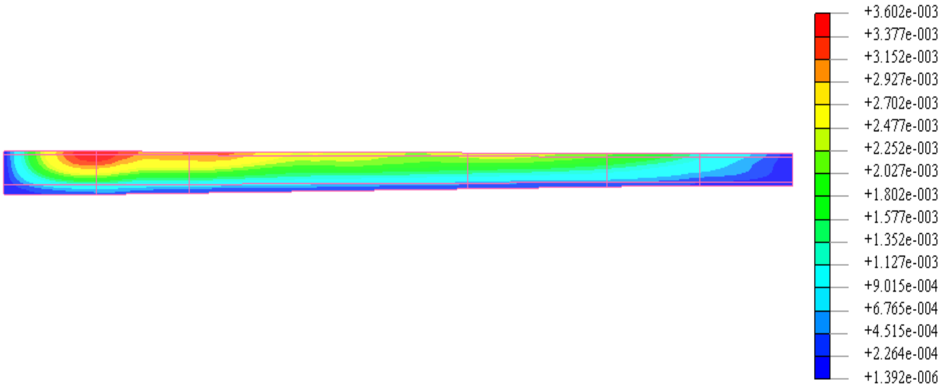


Fig.11 Ground strain distribution in the axial direction in the case1-1

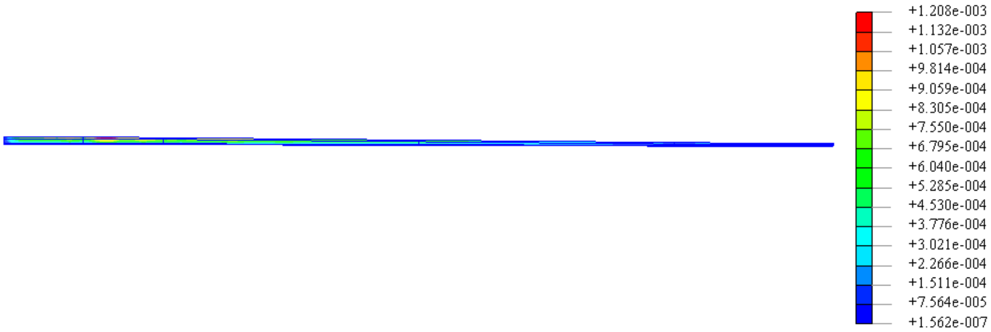


Fig.12 Ground strain distribution in the axial direction in the case2-1

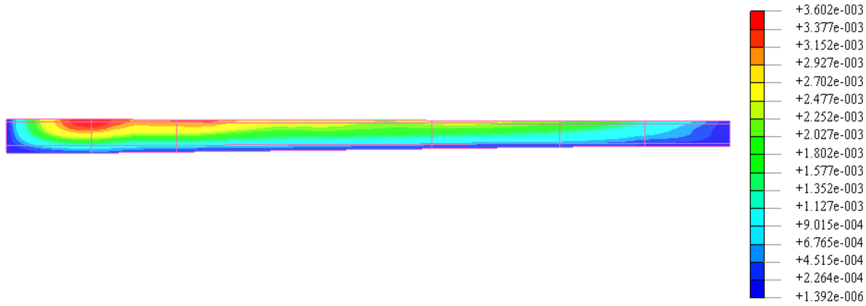


Fig.13 Ground strain distribution in the axial direction in the case3-1

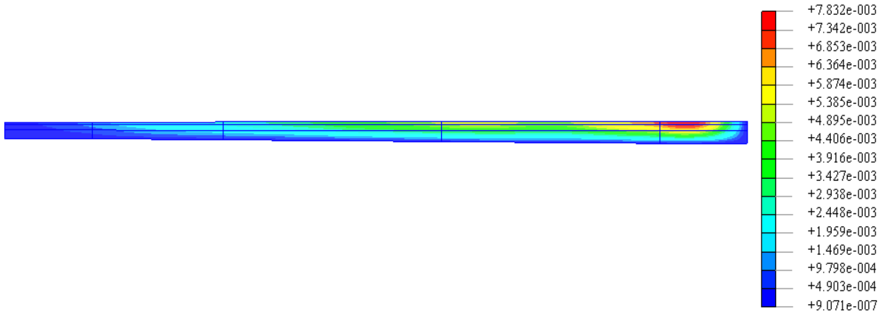


Fig.14 Ground strain distribution in the axial direction in the case4-1

## 6．Comparison of static analysis and dynamic analysis

*6-1 Ground strain*

The seismic water facilities method guidelines define that reference ground strain is obtained by multiplying non-uniformity coefficient by the ground strain obtained by response displacement method in a static analysis, and therefore the ratio C , which is expressed by ground strain obtained by static analysis and that by dynamic analysis (ground distortion ratio C= dynamic analysis ground strain / static analysis ground strain), was calculated for each case as shown in Table 7. The ground strain ratio C was organized for each boundary condition and soil condition of the good and bad grounds based on the result of each case.

The mean value of the ground strain ratio C of the good ground turned out to be greater than that of the bad ground as shown in Table 7 and the greatest mean value was obtained for the microtopography boundary part of the good ground. Ground strain of the good ground obtained by the dynamic analysis is smaller than that of the bad ground though the ground strain ratio C tends to larger. Moreover, the ground strain ratio C for the good ground was greater for the microtopography boundary though that of the bad ground was greater for outside boundaries and therefore differences by boundary conditions are not clear. As seen in the cross sections of CASE3-1 and CASE4-1 in Figures 7 and 8, boundary condition is the parts other than the microtopography boundaries, but depth to the base is different from that to the adjacent microtopography and therefore it is a non-uniformity ground. Therefore, examination based on changes of kinetics of the ground such as proper periods is necessary, we presume.

Table.7 Comparison of the ground strain by static analysis and the dynamic analysis

| CASE | | | 1-1 | 1-2 | 1-3 | 2-1 | 2-2 | 2-3 | 3-1 | 3-2 | 3-3 | 4-1 | 4-2 | 4-3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Microtopography | | | Backswamp | Lowland valley | Dune | Quality gravel plateau | Quality gravel plateau | Quality gravel plateau | Delta・Coastal lowland | Alluvial fan | Backswamp | Quality gravel plateau | Quality gravel plateau | Quality gravel plateau |
| | | | Boundary in the bad ground | | | Boundary in the good ground | | | Outside boundary in the bad ground | | | Outside boundary in the good ground | | |
| Static analysis | Proper period | (s) | 1.056 | 1.032 | 1.688 | 0.268 | 0.304 | 0.340 | 1.944 | 1.500 | 1.044 | 0.836 | 0.176 | 0.092 |
| | Ground classification for the Proper period | | Ⅲ | Ⅲ | Ⅲ | Ⅱ | Ⅱ | Ⅱ | Ⅲ | Ⅲ | Ⅲ | Ⅲ | Ⅰ | Ⅰ |
| | Velocity response spectrum of earthquake vibration in the base ground surface | (cm/s) | 100 | 100 | 100 | 28 | 32 | 45 | 100 | 100 | 100 | 100 | 18 | 8 |
| | Horizontal displacement amplitude of the ground on the pipe axis | (mm) | 213.57 | 208.66 | 341.79 | 14.72 | 19.25 | 30.37 | 393.70 | 303.70 | 211.08 | 168.57 | 5.92 | 1.11 |
| | Wavelength | (m) | 210.48 | 200.33 | 332.72 | 52.56 | 60.81 | 65.88 | 385.06 | 310.19 | 200.60 | 141.10 | 33.80 | 18.07 |
| | Ground strain | (%) | 0.319 | 0.327 | 0.536 | 0.088 | 0.099 | 0.157 | 0.321 | 0.308 | 0.331 | 0.375 | 0.055 | 0.019 |
| Dynamic analysis | The maximum of the ground strain in the shallower than 3m ground | (%) | 0.360 | 0.776 | 0.269 | 0.121 | 0.343 | 0.574 | 0.473 | 0.595 | 0.311 | 0.705 | 0.075 | 0.038 |
| Ground strain ratio (Dynamic/Static) | | C | 1.13 | 2.37 | 0.50 | 1.38 | 3.46 | 3.66 | 1.47 | 1.93 | 0.94 | 1.88 | 1.36 | 2.00 |
| Range | | | 0.50～1.13 | | | 1.00～3.66 | | | 0.94～1.93 | | | 1.36～2.00 | | |
| Average | | | 1.33 | | | 2.83 | | | 1.45 | | | 1.75 | | |

*6-2 Ground strain ratio C and change of the proper periods*

The proper periods of the subsurface ground was calculated from boring data of the adjacent microtopography section used for soil cross section diagrams in the dynamic analysis. Based on the estimation method in the seismic water facilities guidelines, the distortional wave velocity Vs was estimated by N value and proper periods were obtained. Moreover, since it is presumed that variation of kinetics of a ground affects non-uniformity coefficient and variation of proper periods for distance was obtained. The calculation results are shown in Table 8. From these results, relationships between the ground strain ratio C and variation of proper periods were organized for the good and bad grounds. Figure 15 shows its results.

Table.8 Relations of variation of proper periods and the ground strain ratio

| CASE | | | 1-1 | 1-2 | 1-3 | 2-1 | 2-2 | 2-3 | 3-1 | 3-2 | 3-3 | 4-1 | 4-2 | 4-3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Microtopography | | | Backswamp | Lowland valley | Dune | Quality gravel plateau | Quality gravel plateau | Quality gravel plateau | Delta・Coastal lowland | Alluvial fan | Backswamp | Quality gravel plateau | Quality gravel plateau | Quality gravel plateau |
| | | | Boundary in the bad ground | | | Boundary in the good ground | | | Outside boundary in the bad ground | | | Outside boundary in the good ground | | |
| (a)Proper period | | (s) | 1.056 | 1.032 | 1.688 | 0.268 | 0.304 | 0.340 | 1.944 | 1.500 | 1.044 | 0.836 | 0.176 | 0.092 |
| Ground strain ratio (Dynamic/Static) | | C | 1.13 | 2.37 | 0.50 | 1.38 | 3.46 | 3.66 | 1.47 | 1.93 | 0.94 | 1.88 | 1.36 | 2.00 |
| The adjacent microtopography | The distance between the boring | (m) | 650 | 610 | 700 | 840 | 670 | 800 | 720 | 500 | 600 | 650 | 500 | 500 |
| | Boring date name | | F-h-24 | D-I-1 | E-h-4 | 56381542001 | V-c-12 | F-h-59 | N0159+10 | F-H-26 (F-H-46) | D-h-1 | Y-a-7 | 55387653002 | Y-a-31 |
| | Microtopography | | Natural levee | Quality gravel plateau | Backswamp | Lowland valley | Alluvial fan | Backswamp | Delta・Coastal lowland | Alluvial fan | Backswamp | Quality gravel plateau | Quality gravel plateau | Quality gravel plateau |
| | (b)Proper period | (s) | 0.780 | 0.412 | 1.292 | 0.112 | 0.804 | 1.268 | 1.296 | 0.760 | 0.808 | 0.628 | 0.296 | 0.284 |
| | Ground classification for the proper period | | Ⅲ | Ⅱ | Ⅲ | Ⅰ | Ⅲ | Ⅲ | Ⅲ | Ⅲ | Ⅲ | Ⅲ | Ⅱ | Ⅱ |
| Variation of proper periodsd (a-b) | | (s) | 0.276 | 0.620 | 0.396 | 0.156 | 0.500 | 0.928 | 0.648 | 0.740 | 0.236 | 0.208 | 0.120 | 0.192 |
| Variation of proper periods (Variation of proper periods per 1km) | | (s/km) | 0.425 | 1.016 | 0.566 | 0.186 | 0.746 | 1.160 | 0.900 | 1.480 | 0.393 | 0.320 | 0.240 | 0.384 |

The results revealed that the ground strain ratio C becomes large when variation of proper periods is great for the neighboring ground. Moreover, the ground strain ratio C of the good ground becomes larger than that of the bad ground for the same amount of change in proper periods. Velocity response spectrum used for design described in the seismic water facilities guidelines is used for the static analysis, and reference ground strain is small in the case of the good ground and its ratio with strain obtained by the dynamic analysis became large, we presume. Since the velocity response spectrum described in the seismic water facilities guidelines is used for normal design, similar results would be obtained, we suppose.

In the seismic water facilities guidelines, non-uniformity coefficient in diluvial grounds is assumed 1.0 in the case of obtaining reference ground strain by a static analysis, except for the topography which is not flat as shown in Table 1. However, on a good ground such as diluvial grounds, the ground strain ratio C becomes large for variation of kinetics of the ground such as proper periods. Therefore, judging not only by ground in pipleline embedding point but also by microtopography boundaries in a microtopography classification map and past boring data, "non-uniformity" or "extremely non-uniformity" coefficient needs to be adopted for the location where variation of proper periods is large.

Further, since ground strain obtained by a static analysis is small for a good ground such as diluvial grounds, reference ground strain is small even if multiplying by non-uniformity coefficient.

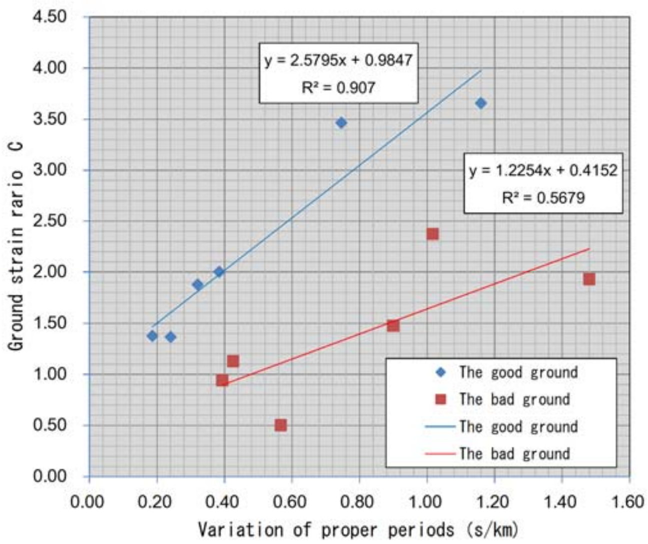


Fig.15 Relation of variation of proper periods and the ground strain ratio C

## 7. Conclusion

(1) The aim of this study was to discuss non-uniformity coefficient of a ground for earthquake-resistant for pipelines, which are one of the embedded pipes. The authors studied focusing on microtopography sections and their boundaries by static and dynamic analyses, based on information on damages locations of the 2004 Niigataken Chuetsu earthquake and the 2007 Niigataken Chuetsu offing earthquake, which are the earthquakes recently occurred. As a result, the followings have been clarified.

a) For mean values of the ground strain ratio C for microtopography boundaries and the outside boundaries for good and bad grounds (ground strain obtained by a dynamic analysis / ground strain obtained by a static analysis), it has been clarified that the greatest value is seen for the boundary of the good ground and the non-uniformity coefficient tends to greater in the boundary of the good ground.

b) Study on the relationship between the rate of change of proper periods, which indicate degrees of sudden change of the ground, and ground strain ratio C revealed that the ground strain ratio C becomes larger when variation of proper periods is great.

c) The results of comparison of the ground strain ratio C for the bad ground with that of the good ground have revealed that the ground strain ratio C of the good ground becomes larger than that of the bad ground for the same amount of change in proper periods. Therefore, for the ground strain obtained in the static analysis, when proper periods change caused by non-uniformity of the good ground, the ground strain greatly varies.

d) The ground strain ratio C becomes large for variation of kinetics of a ground such as proper periods for a good ground such as diluvial grounds. Therefore, "non-uniformity" or "extremely non-uniformity" coefficient needs to be adopted for the location where variation of proper periods is large, judging not only by ground in pipeline embedding point but also by microtopography boundaries in a microtopography classification map and past boring data.

(2) For non-uniformity coefficient of embedded pipes, there have been no studies that focused on a microtopography classification map and boundaries of microtopography and it is believed that acquiring relationship between variation of proper periods and the ground strain ratio C will allow us to obtain a certain index. However, velocity response spectrum in a static analysis and seismic waves in a dynamic analysis in this study are generally opened and used for design. Moreover, for ground cross sections, since a stratum line is estimated linearly based on boring data of two points, it is not evaluated quantitatively as a non-uniformity coefficient. Therefore, in the future, it will be necessary to build a local ground model and clarify non-uniformity coefficient quantitatively, the authors suppose.

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