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# Numerical analysis of dip-slip fault displacement affected by railway structure foundation

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ABSTRACT: When any kind of structure is being constructed, the effect of fault induced permanent ground deformation on structural behavior should always be kept in mind and this type of area should be avoided. But there are unavoidable cases with railway structure. In the Railway Technical Research Institute, an experiment was conducted with two cases. Case 1 is the case where there is no structure (when there is no structure foundation), and case 2 is the case where the structure foundation is installed on the model ground. In the experiment, they studied a qualitative comparison of the occurrence of the shear band with and without a structure foundation and adopted the experiment in a gravitational field. Additionally, the study focused on the calculation results of the longitudinal shear strain distribution for both cases and made a comparison between them. The main aim of my research is to reproduce the experiment conducted by Railway research institute by making numerical models (with and without structure) using the Discrete Element Method (DEM) and compare the numerical result with the experimental one. DEM is considered suitable for numerical analysis of fault displacement. It is needed to be mentioned that Numerical analysis simulation has the advantage of being able to observe temporal changes and the inside of the ground, which are difficult to observe in field surveys and model experiments. By comparing the numerical models (with and without structures), it is confirmed that due to the existence of a structure foundation, the shear band that developed to ground surface tends to avoid directly under the structure and the deformation mode was such that the ground on the left side of the foundation acts as a solid mass.

## 1 INTRODUCTION

The consequence of earthquake damage on the structure is always severe. The interaction of faults with foundations has received little attention apart from field reconnaissance work and questions remain about suitable methods to design foundation in faulting zones. Some research has done regarding building foundation (laboratory conditions) (Cole et al. 1984) and (numerical study) (Bransby et al. 2008). More research attention is needed for structures; build across the fault line especially when sometimes it is unavoidable to construct structures like railway and roadway above fault line. In Railway Technical Research Institute, Japan an experiment was conducted with two cases. Case 1 is the case where there is no structure foundation and case 2 where the structure foundation is installed on the model ground. In the experiment, they studied a qualitative comparison of the occurrence of the shear band with and without a structure foundation.

This study aims to reproduce the experiment conducted by Railway Technical Research Institute numerically and compare the numerical result with the experimental one.

## 2 OVERVIEW OF PAST EXPERIMENT

As the purpose of the experiment was related to the generation of the shear band, the main things to be considered here is gravity and centrifugal fields. This experiment was conducted in a gravitational field and the model used in the experiment was constructed in scale 1/25 of the actual structure. In an experiment of a centrifugal force field, it is possible to reproduce a stress state like that of a real object, which is suitable for quantitative evaluation. But in this case, the thing to be kept in mind is that handling this type of experiment is very much difficult. On the other hand, in the experiment of the gravitational field, the stress state assuming the real thing cannot be reproduced, but it is advantageous as a means for conducting the experiment, measuring the response amount, observing the phenomenon and most importantly examining the qualitative tendency. In the case of this experiment, the main objective was to compare the occurrence of shear bands with and without a structure foundation. For serving this purpose, the experiment was adopted in a gravitational field.

### 2.1 *Experimental Equipment*

A large fixed soil tank was used for this experiment. The ground of that soil tank was constructed with dry sand on the test device. The layer thickness of the ground was 1.0 meter. A test device for simulating vertical fault displacement was installed in the soil tank. After creating the ground on the model device, the vertical displacement was the impute to simulate the occurrence of longitudinal fault displacement. Here two cases were considered. Firstly, the ground was tasted with the absence of a structure model. After finishing that, again, the ground was tested with the presence of a structural model.

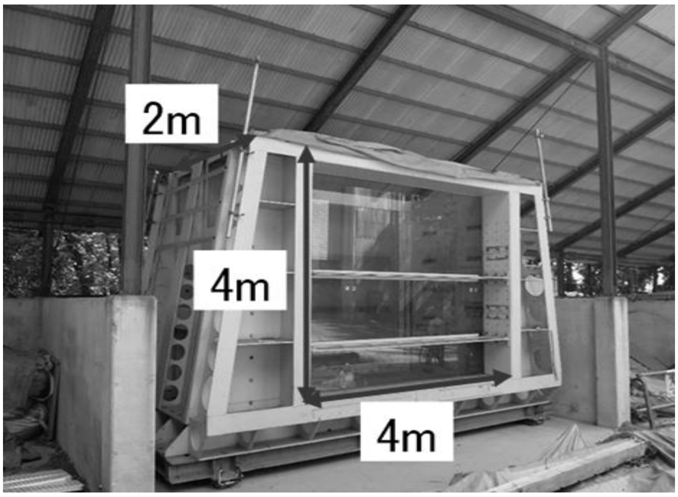



Figure 1. Earth tank used in the experiment.

## 3 NUMERICAL MODELLING

### 3.1 *DEM Method*

The DEM method developed by Cundall and Strac (Cundall et al. 1979) is an important tool for modeling the behavior of granular materials. The basic algorithm of the DEM is based on the finite difference formulation of the equation of motion. The kinetic equation is formulated based on Newton's second law of motion. An explicit time marching scheme is used to directly solve the equations of motion. In the conventional DEM, each contact is represented by a set of springs, dashpots, no-tension joints, and a shear slider, which response to a contact force acting on the slider. The normal contact force (fn) and the tangential contact force (ft) must be balanced against the resistance supplied by the springs and dashpots.

### 3.2 *Proposed Numerical Model*

The general view of the model used for the analysis is shown in Figure 2. The whole analysis is mainly carried out in two phases: the sedimentation process and application of fault movement. Toyoura sand’s property has been used in this study.

### 3.3 *Sedimentation Process*

More than 2 million of individual spherical particles are used to generate the models. Each individual particle is modeled separately, and motion is calculated step by step based on interaction with the neighboring particles. In the model, spherical particles are applied with normal, shear and rolling springs as well as normal and shear dashpots. Due to the limited time frame, spherical particles are proposed with mentioned particle sizes rather than irregular particles. During the computation, to minimize the calculation time eight CPU are used parallelly.

After the arrangement of particles, the model should be packed properly to decrease the void ratio before the application of fault movement. The particles are freely released from the original position. For the sedimentation process, the only gravity force is used to makes the particles settled. After completion of sedimentation, the final height of the soil becomes 1 meter.

Table 1. Parameters of granular particles used in models.

| Parameters | Value |
|---|---|
| Particle Radius | 1.05 cm ~ 1.75 cm |
| Spring Constant (tangential direction) | 3.00 x 109 N/m |
| Spring Constant (normal direction) | 1.0 x 109 N/m |
| Normal Damping Constant | 1.4 x 105 Ns/m |
| Tangential Damping Constant | 8.0 x 104 Ns/m |
| Particle Density | 2600 kg/m3 |
| Coefficient of friction | 0.2 |

### 3.4 *Application of Fault Displacement (Ground Only Model)*

The whole model is divided into two parts: the rising side, stationary side. The length of the rising side is 120 cm and the length of the stationary side is 180 cm. The rising side moves upward with a velocity of 0.04 m/sec floor and sidewall for generating fault in the model i.e. in the z-direction of the model.

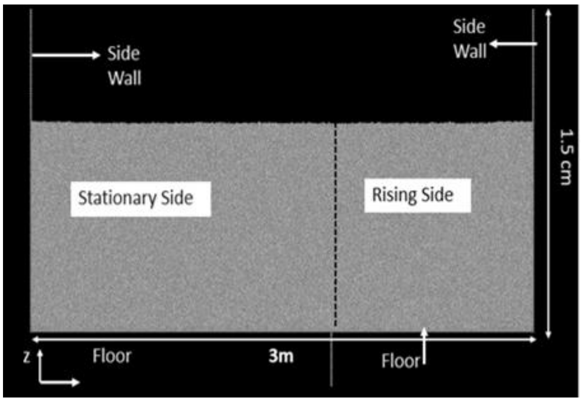



Figure 2. Schematic of the numerical model used in the analysis.

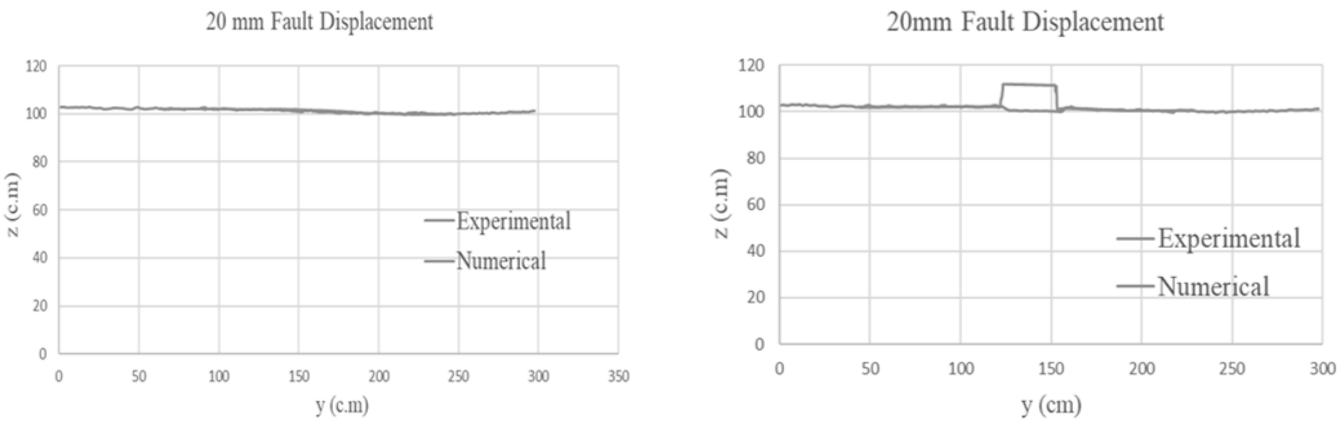
### 3.5 *Application of Fault Displacement (Structure above the Ground)*

In order to reproduce the weight of the model experiment, a total weight of 40 g is given to the simulated particles consisting of a total of 5120 pieces and the total weight is 204.8 kg which is close to the experiment. To prevent the ground from getting rough when placing large particles, the structure particles were moved to a position slightly higher compared to the ground height after the creation of ground and arranged in free fall. Besides, the parameters and coefficient of friction at the time of ground creation were considered the same as the reproduction analysis of the fault displacement experiment without structure.

## 4 RESULT AND DISCUSSION

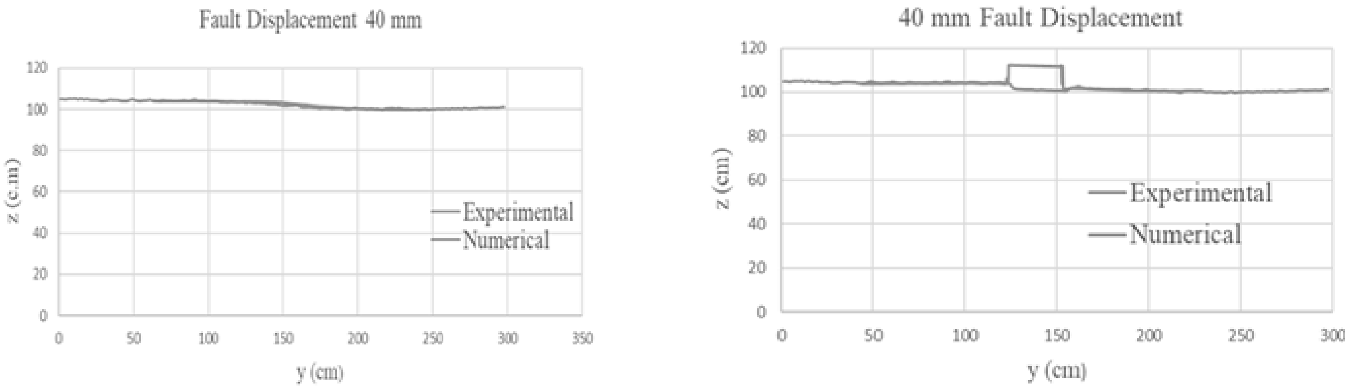
### 4.1 *Comparison of Experimental & Numerical Model (Without Structure)*

In the Experiment conducted by National Railway Research Institute, the sensor for measuring the ground surface measures the vicinity of the fault occurrence point, and 725 mm from the fault displacement occurrence point to the rising side, and 1115 mm on the fixed side. As a result, we have the data near the fault displacement occurrence point. Figure 3a, Figure 4a, Figure 5a gives a Comparison of Experimental & Numerical Model (without structure) up to at-fault displacement 20mm, 40mm, 60mm respectively. The approximate shape of the ground surface for the experimental & numerical Model is almost the same. So, it can be said the numerical model of ground (without structure) is sufficiently justified.



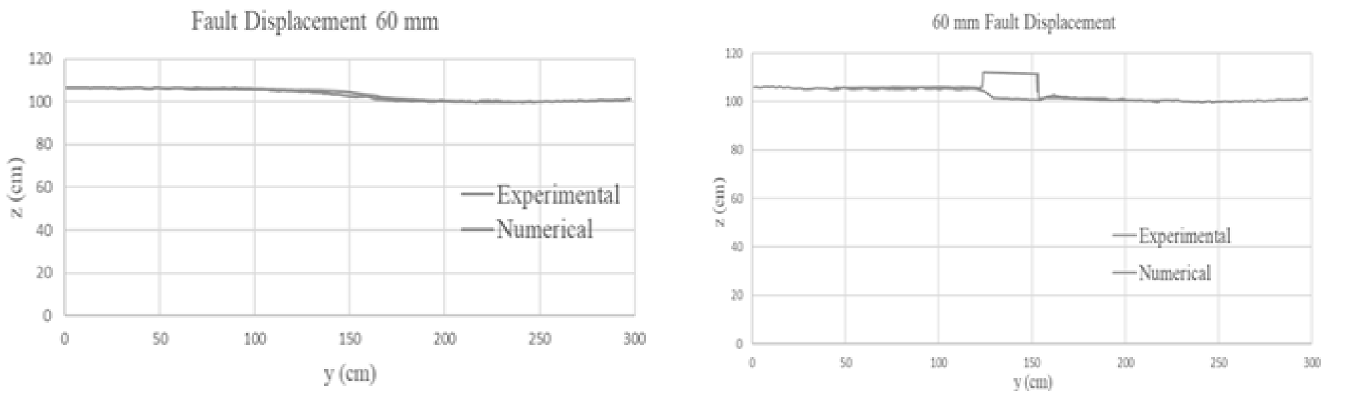

(a) (b)

Figure 3. Comparison of experimental & numerical model (Fault Displacement 20mm (a) Without structure (b) With structure.




(a) (b)

Figure 4. Comparison of experimental & numerical model (Fault Displacement 40mm (a) Without structure (b) With structure.




(a) (b)

Figure 5. Comparison of experimental & numerical model (Fault Displacement 60mm) (a) Without structure (b) With structure.

### 4.2 *Comparison of Experimental & Numerical Model (With Structure)*

The ground surface created from the data in the experiment (with structure) conducted by National Railway Research Institute is compared with the numerical model that we created by DEM (with structure). In this study, the fault displacement occurrence point is analyzed by shifting from the structure to a rising point and it is moved to 200mm to match with the created numerical model. Figure 3b, Figure 4b, Figure 5b presents a comparison of the Experimental & Numerical Model (with structure) up to 20 mm, 40 mm, and 60 mm respectively at fault displacement. For the experimental & numerical model, the approximate ground surface shape is almost the same. So, the numerical ground model (with structure) can be stated to be acceptable enough.

## 4.3 *Comparison of Ground Shape after Applying Different Fault Displacement*

From Figure 6 and Figure 7 we observe, in the numerical model, both cases (with and without structure) show the same result in ground surface condition up to displacement 20-30 mm but after that, a clear difference is seen in the ground surface behavior. For the ground without any structure as the bottom displacement progressed, the generation of the shear band is confirmed on the rising side.

On the other hand, for the ground with the structure, it can be observed that the ascending ground rises almost uniformly and the ground on the left side of the foundation becomes a solid mass and act as a deformation mode that rises.

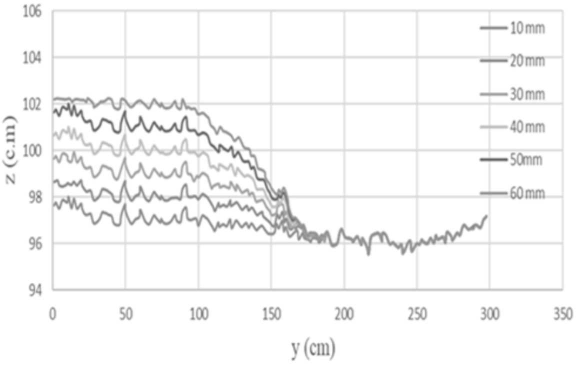



Figure 6. Comparison of ground shape after applying different fault displacement (Without Structure).

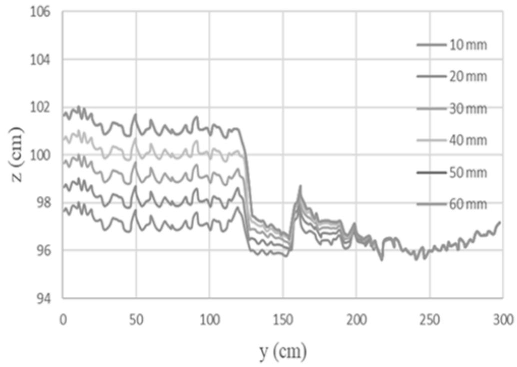
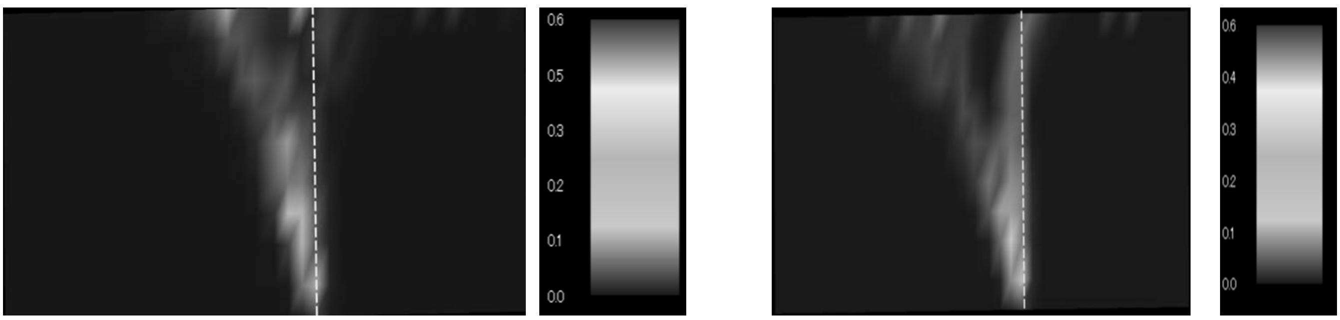



Figure 7. Comparison of ground shape after applying different fault displacement (With Structure).

## 4.4 *Development of Shear Band*

With the increase of displacement, the first shear band development point becomes closer with the point of fault displacement in case of ground without structure and the value of longitudinal shear strain near the ground surface becomes higher. On the other hand, when there is a structure over the ground, if the displacement is increased, the strain gets bigger, but the propagation nature of the shear band is different from the ground only model. The strain, in this case, is just through the point where fault displacement is applied.




(a) (b)

Figure 8. Development of shear band at 20 mm (a) without structure (b) with structure.


(a) (b)

Figure 9. Development of shear band at 40 mm (a) without structure (b) with structure.


(a) (b)

Figure 10. Development of shear band at 60 mm (a) without structure (b) with structure.

From Figure 8, Figure 9 and Figure 10 give us a clear view of the development of the shear band. When 20 mm displacement is applied at the bottom of the numerical model (without structure and with structure), the amount of strain near the ground is very low and no noticeable shear band was developed.

When 40 mm displacement is applied on the ground only model, the first share band was developed at 370.56 mm. On the other hand, when the footing exists over the ground, the strain generated through the point where the fault displacement is applied, and the first shear band is developed at 69.26mm. The same behavior is seen in the case of 60 mm fault displacement.

## 5 CONCLUSIONS

Dip Slip Fault Displacement Affected by Railway Structure Foundation has been analyzed numerically in this research. It is always good to avoid fault lines while constructing such types of structure but sometimes such types of situations are unavoidable. So, an experiment was conducted by Railway Technical Research Institute, Japan. The major purpose of that research was to understand the difference in the behavior of the ground surface when there is no structure over the ground and when there is a structure over the ground. In the test, the bottom of the layered sand was investigated through a scaled static jack to simulate a dip-slip fault.

The main aim of this research is to reproduce the experiment conducted by the Railway Technical Research Institute by making numerical models (with and without structure) using the Discrete Element Method (DEM). From the numerical study, it was seen that in the experiment, both cases (with and without structure) show the same result in ground surface condition up to displacement 20-30 mm. However, after 30 mm, a clear difference is seen in the ground surface behavior. For the ground without any structure, as the bottom displacement progressed, the generation of the shear band is confirmed on the rising side. On the other hand, for the ground with the structure, it can be observed that the ascending ground rises almost uniformly and the ground on the left side of the foundation becomes a solid mass and act as a deformation mode that rises due to the existence of the structure foundation, the shear band that developed to the ground surface tends to avoid directly under the structure which completely justifies the experimental observation. In the future, this model can be used to understand Soil structure interaction above any fault line for the railway structure foundation.

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