The strain energy development on subsoil-embankment because of seismic wave direction

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Abstract. The strain energy is associated with seismic embankment resistance and it needs more examine for understanding types of embankment collapse owing to the morphology of nonlinear deformation occurrence on the subsoil-embankment because of the applied seismic wave at different directions. In this study, a numerical simulation was performed to assess the strain energy function on subsoil-embankment because of the seismic wave in different directions. The seismic wave of three directions separately numerically was applied on the embankment-subsoil model and the strain energy development at each model was compared. This type of embankment seismic design has not been described in the literature by means of ABAQUS, for assessing the embankment seismic failure mechanism. The results reveal that the strain energy morphology associated with the direction of the seismic wave controls the failure mechanism of the subsoil-embankment. The direction seismic wave could be produced strain energy up to 10%, and this strain energy causes the morphology of nonlinear deformation of the model. The founding of this simulation is supportive in understanding a relationship between strain and seismic wave types of embankment collapse.

1. Introduction
The strain energy has three important characteristics which are density, acceleration, and dissipation. However, each of these characteristics could be effective in the nonlinear deformation of the subsoil-embankment model and govern the subsoil-embankment collapse mechanism.

The strain mechanism has numerically been investigated at subsoil when the subsoil is subjected to seismic excitation and surcharge, and differential displacement of the soil foundation was investigated [1-3], while the in the nonlinear deformation of the subsoil has not been studied perfectly.

The subsoil-embankment seismic resistance and collapse because of applied dynamic loading were investigated. The seismic stability of loose sandy embankment strengthened by dense zone [4-5], reinforcement characteristics for seismic stability of embankments [6], the compaction effect on the seismic resistance of gravelly embankment [7] and the thermal transfer of a crushed-rock embankment seismic stability was studied [8]. Several types of soil foundation and embankment seismic stability were studied [1-8], while the strain energy mechanism was not clarified perfectly with respect to the seismic wave direction. There is an unknown understanding of the strain energy development on subsoil-
embankment because of seismic wave direction which is causes the nonlinear deformation of the subsoil-embankment develops. In this study, a numerical simulation was performed to assess the strain energy function on subsoil-embankment because of the seismic wave in different directions. The seismic wave of three directions separately needed to apply on the embankment-subsoil model for realizing strain energy development and comparison of strain energy at each model is very important in designing seismic stability of the subsoil-embankment for realizing the nonlinear deformation of the subsoil-embankment.

2. Modeling
The subsoil-embankment was modeled and subjected to seismic loading at three different directions at each stage of numerical analysis. The Embankment made of 2 (m) height and top level of 3 (m) and with the bottom of 9 (m), and characterized width of 3 (m) for both embankment and subsoil. The length of (15) and height of 1.5 (m) were selected for the subsoil. Figure 1 is shown the two-dimensional view of the subsoil-embankment.

![Figure 1](image1.png)

**Figure 1.** The embankment-subsoil model was subjected to seismic excitation

![Graphs](image2.png)

**Figure 2.** The seismic acceleration was applied to the embankment-subsoil model [10].
The mechanical properties of soil are shown in table 1, and subsoil and embankment made with a soil which has the modulus elasticity 20 (MPa), Poisson’s ratio of 0.3, friction angle of 30 degree, dilatancy angle of zero degree, cohesion 3 (kPa) and unit weight of 1850 kg/m³. The mechanical properties of the soil in the soil and embankment are selected the same to avoid the interaction of the material which may change the seismic wave propagation.

The subsoil-embankment was excited by three component of the near-fault ground motion have been reported in the literature [10]. The seismic data used in the numerical analysis is shown in figure 2. The acceleration histories at X, Y and Z directions have a different attitude. The highest amplitude in the X direction is more than Y and Z direction and also the highest amplitude in the X direction occurs before Y and Z directions. The frequency at X, Y and Z directions are different. The ABAQUS software used in numerical analysis.

According to the simulation process, the model boundary condition made with the subsoil is rested on a rigid place and seismic load applied in three different directions at each stage. And the results of the three stages of numerical analysis have been compared. The near-fault ground motion and forcing frequency are applied to each model in the two steps of the numerical analysis. In applied forcing frequency on the model first six modes have been selected in the numerical analysis. The first six modes of forcing frequency are basic modes and are very important.

### 3. Analysis and discussion

The subsoil-embankment has associated seismic resistance, this subsoil-embankment seismic interaction occurs because of internal loads interaction and the failure of the embankment is related to subsoil seismic response and it influences embankment serviceability.

Figures 3 and 4 show that the frequency and amplitude at X, Y and Z directions are different and cause developing different subsoil-embankment seismic responses and appeared in the form of the nonlinear stress and strain. However, with different frequencies and amplitudes, the type of failure is changed. With the attention, the component of the near-fault ground motion the types of vibration at each direction of X, Y and Z has different characteristics, and this kind of vibration leads to three types of subsoil-embankment the morphology of nonlinear deformation of the model. The maximum stress-strain is observed at the toe of embankment when the model is subjected to X-direction seismic excitation and, the maximum stress-strain is observed at the subsoil when the model is subjected to seismic excitation from the direction of Y direction. However, the combination of the seismic excitation at three directions of the X, Y, and Z results in developing nonlinear deformation of the model. The stress at the vertical direction is nine-time less than the maximum stress horizontal.

The subsoil-embankment nonlinear deformation of the model is changed through the strain energy development on subsoil-embankment because of seismic wave direction. The mechanism of strain energy morphology associated with the direction of the seismic wave and it controls the failure mechanism of the subsoil-embankment. The direction of the seismic wave produces the variation of maximum of strain energy up to 10%, at two different vertical and horizontal directions and this strain energy causes the morphology of nonlinear deformation of the model. Beyond the magnitude of the strain energy, the direction of releasing strain energy significantly influences on the subsoil-embankment nonlinear deformation and collapse mechanism of the model. The strain at Z direction causes the embankment over turning while the strain energy at the Y direction produces the vertical densification of the subsoil-embankment. The strain energy development on subsoil-embankment because of seismic wave direction is leads to embankment deformation changes at each stage of loading, unloading and reloading. The strain energy release at each direction could be significantly important in seismic stress-strain behavior and variation of the

### Table 1. Mechanical properties of soil [9].

| Soil type | Modulus elasticity, E (MPa) | Poisson’s ratio, ν | Friction angle, ϕ (degree) | Dilatancy angle, ψ (degree) | Cohesion, c (kPa) | Unit weight, γ kg/m³ |
|-----------|----------------------------|------------------|---------------------------|---------------------------|------------------|----------------------|
| Soil B    | 20                         | 0.3              | 30                        | 0                         | 3                | 1850                 |
mechanical properties of the subsoil-embankment when the model is under nonlinear vibration at different direction. The founding of this simulation is supportive in understanding a relationship between strain energy mechanism which is developed by seismic wave direction and seismic wave types of embankment collapse, and the seismic design of the infrastructure is related to seismic wave propagation at all three directions. However, not only highest amplitude and high level of the frequency is important in the seismic design of the subsoil-embankment, the nature of strain energy at each direction owing the seismic wave types is important in the subsoil-embankment nonlinear deformation and collapse.

Figure 3. Stress (MPa) developed at subsoil-embankment model
4. Conclusion
The subsoil-embankment was modeled using a same soil and the model was subjected to seismic loading at three different directions at each stage of numerical analysis, and along the near-fault ground motion, the forcing frequency is applied on the model during the perform numerical analysis. In this study, the strain energy development on subsoil-embankment because of seismic wave direction investigated through the three-dimensional numerical analysis. The direction of the seismic wave produces the variation of strain energy at two different horizontal and vertical directions and this strain energy causes the morphology of nonlinear deformation of the model. The direction of the seismic wave produces the variation of maximum of strain energy up to 10%, at two different vertical and horizontal directions and this strain energy causes the morphology of nonlinear deformation of the model. However, not only highest amplitude and high level of the frequency is important in the seismic design of the subsoil-embankment, the nature of strain energy

Figure 4. Strain variation at the subsoil-embankment model
at each direction owing the seismic wave types requires to consider in the subsoil-embankment nonlinear deformation and collapse prediction.

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