Seismic Design of a Nuclear Waste Repository against an Earthquake Induced Rock Shear Load – 15346

Young-Chul Choi*, Heui-Joo Choi*
*Korea Atomic Energy Research Institute

ABSTRACT

Concepts for isolation of spent nuclear fuel have been studied by organizations in countries that employ nuclear power. These concepts typically involve a deep geological repository in bedrock, with processed radioactive waste encased in deposition canisters emplaced in underground excavations and surrounded by clay-based buffer. This multi-barrier approach is intended to provide long-term isolation of the waste package from the biosphere. According to many statistics, there is a tendency toward increasing numbers of earthquakes in the Korean peninsula each year. If an earthquake induced rock shear load occurs at a repository site, the engineered barrier system(EBS) can be sheared, resulting in a pressure increased in the buffer material. This is expected to result in damage to the canisters. Therefore, because the damage, which can be fatal to a disposal canister, can be given in case an earthquake occurs, the method protecting the canisters safely is needed. In this paper, “an earthquake-resistance type buffer” was proposed using a method for protection from earthquake damage. To aid in achieving this objective, we have developed a technique for estimating the behavior of the EBS affected by earthquake induced rock shear using an analysis method, such as finite element method. As a first step, experimental tests are performed for understanding the behavior of the buffer material. Comparing the results of the numerical simulations to the experimental results can be used to verity the reliability of the analysis model. Then we developed the real scale analysis model of a nuclear waste repository. The main parameter having an effect on the earthquake-resistant performance was analyzed and an earthquake-resistance proof type buffer was designed. To improve the earthquake-resistance performance, we designed the buffer by putting the low-density buffer between the canister and buffer. The simulation results show that the earthquake-resistant performance was improved by about 65%.

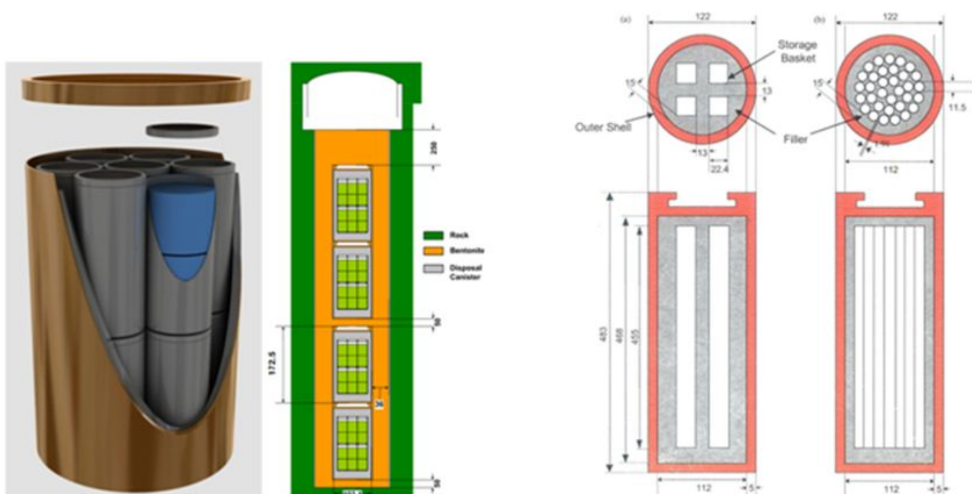
INTRODUCTION

In an underground depth of 500m, a high-level radioactive waste disposition system is made by boring the tunnel in the base rock and putting the high level waste disposal canister that is the surrounding the form with the buffer material as show in Fig.1. According to many statistics, there is a tendency toward increasing numbers of the earthquakes in the Korean peninsula each year. Therefore, because the damage, which can be fatal to a disposal canister can be given in case an earthquake occurs, the method protecting the disposal instrument safely is needed. In this paper, an earthquake-resistance type buffer was developed using a method for protection from earthquake damage. The main parameter having an effect on the earthquake-resistant performance was analyzed and an earthquake-proof type buffer material was designed. A shear analysis model was developed and the performance of the earthquake-resistance buffer material was evaluated.

Fig. 1 The high level radioactive waste disposal system.

NUMERICAL MODEL FOR A SHEAR MODEL

The shear rate due to earthquakes with magnitudes of greater than 6.5 averages around 0.8m/sec, and the calculated shear displacement is 0.079m[1~2]. Taking this into account, this paper focuses on the fault movement with displacement on the order of 0.1m and shear rates of about 1m/sec.



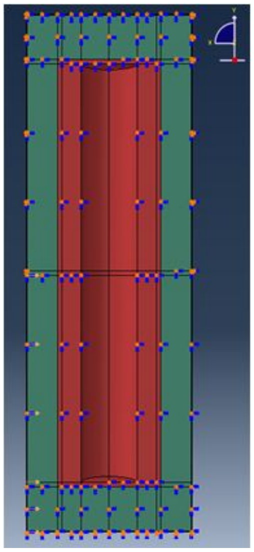
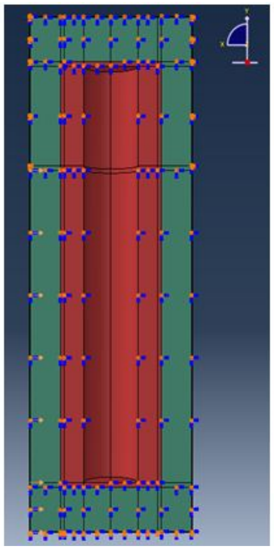
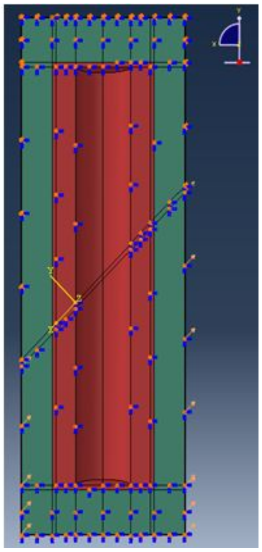
(a) (b) (c)

Fig. 2 (a) Ceramic disposal canister, (b) PWR disposal canister, (c) CANDU disposal canister

Disposal canisters can be divided into the ceramic disposal canisters, PWR disposal canisters and CANDU disposal canisters. Because the length is longer than the diameter in the case of a CANDU disposal canister, the structurally weak a CANDU disposal canister was selected to develop an ‘earthquake-resistance buffer’.

The reliability of the numerical model is tested through a comparison with the available range of experimental results. The 3-dimensional, non-linear, finite element model utilizes the computer code ABAQUS.

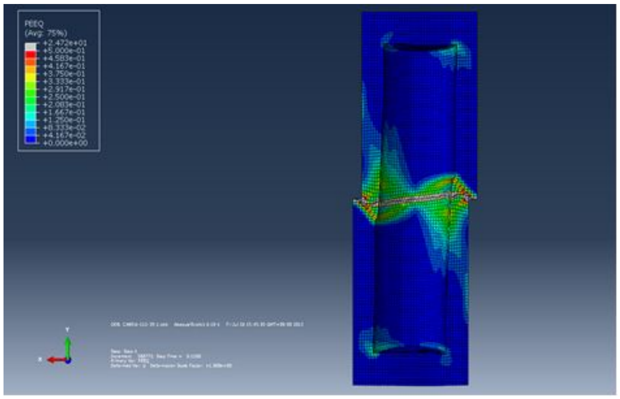
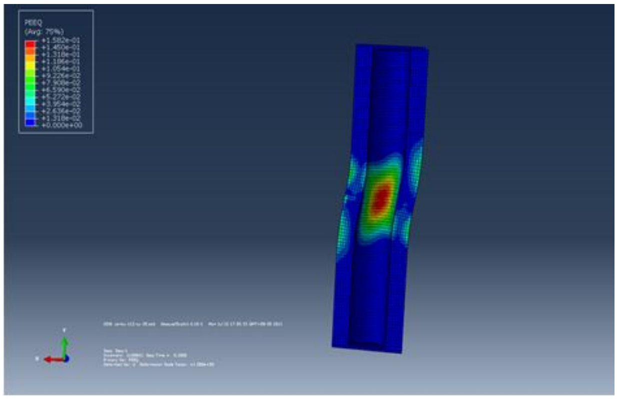
There are many types of a shear displacement due to earthquake in the disposal system. In the paper, the analysis was carried out for three kinds of a shear direction as shown in Fig.3. Fig.3(a) shows a case where the shear displacement occurs in the horizontal direction at the center.(CASE 1) Fig.3(b) shows a case where the shear displacement occurs in the horizontal direction at the 3/4 point from the bottom of the disposal system. (CASE 2) And Fig.3(c) explains a case shear displacement is generated in 45° inclined at the center. (CASE 3)

(a) (b) (c)

Fig. 3. Numerical model as shear directions. (a) case 1, (b) case 2, (c) case3

NUMERICAL RESULTS ACCORDING TO THE SHEAR DIRECTIONS

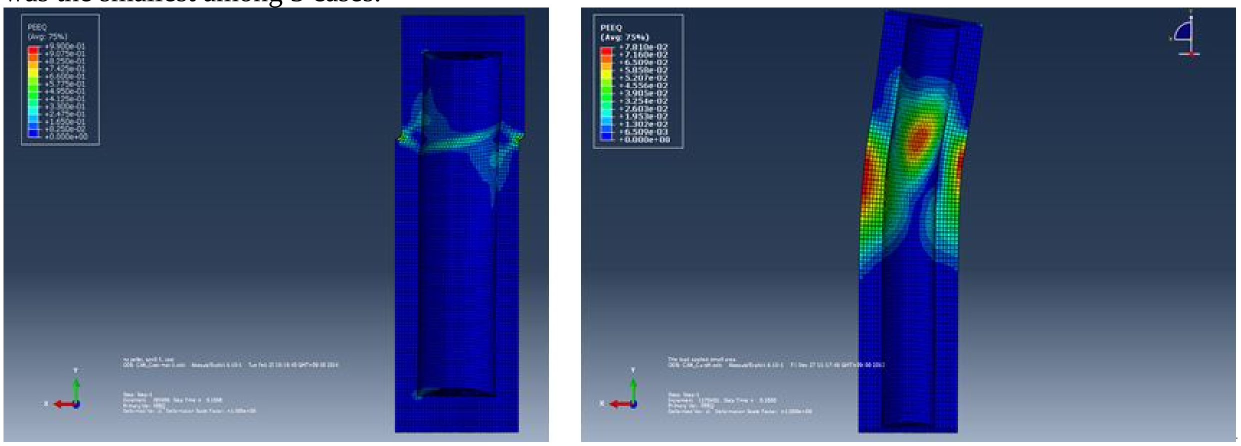
(a) (b)

Fig. 4 ABAQUS analytic results for the case 1 after 0.3m shear displacement. The plastic strain distributions (a) in the buffer and (b) in the canister.

Fig. 4 shows the strain distributions of the buffer and canister for the CASE 1. The strain of the buffer showed X-shaped distribution. The maximum strain of the canister is generated in the side of the canister. This is because the canister was the cylindrical of which the inside is vacant.

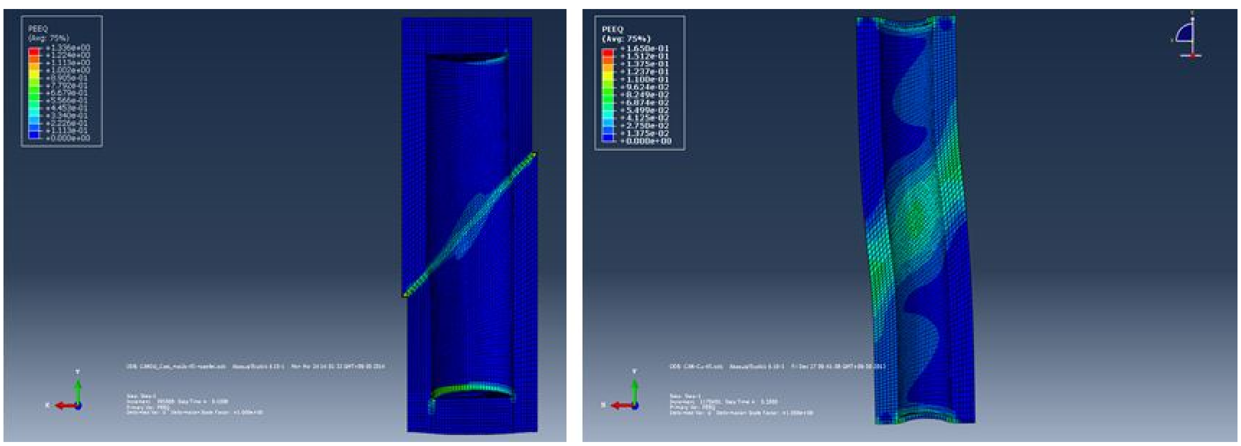
Fig. 5 shows the strain distributions of the buffer and canister for the CASE 2. The strain of the buffer showed X-shaped distribution like CASE 1. Unlike CASE 2, the maximum strain of the canister is generated in the direction of shear. In addition, the strain was distributed widely in comparison with CASE 1.

Fig. 6 shows the strain distributions of the buffer and canister for the CASE 3. The strain of the canister was the smallest among 3 cases.



(a) (b)

Fig. 5 ABAQUS analytic results for the case 2 after 0.3m shear displacement. The plastic strain distributions (a) in the buffer and (b) in the canister.



(a) (b)

Fig. 6 ABAQUS analytic results for the case 3 after 0.3m shear displacement. The plastic strain distributions (a) in the buffer and (b) in the canister.

NUMERICAL RESULTS FOR THE EARTHQUAKE-RESISTENT PERFORMANCE

The previous results show only the case when shear displacement is 0.3m and shear rate is 1m/sec, but they don't show the performance of an earthquake-resistant. In order to compare or evaluate seismic performance, an evaluation factor is needed. In this paper, the shear displacement value which the greatest plastic strain increase in the canister was selected as the estimation factor as shown in Fig. 7.

Fig. 7 shows the strain change about the shear displacement at the point which the maximum plastic strain is generated in the canister. When the shear displacement increases, the point which the strain rate increases suddenly is the place where the plastic fracture occurs. It means that canister of about shear displacement can endure about 0.1m in the Fig. 7.

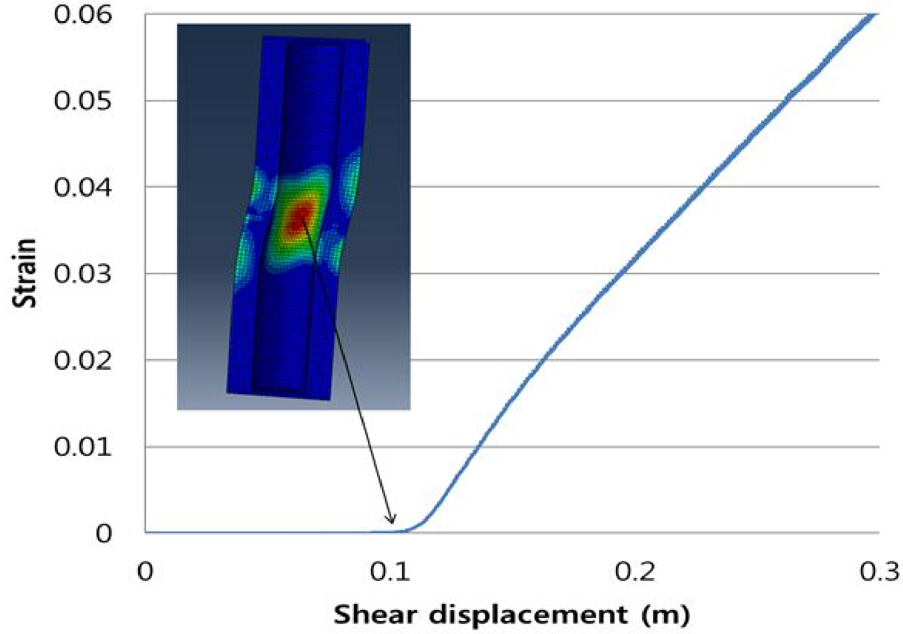


Fig. 7 Earthquake-resistance parameter.

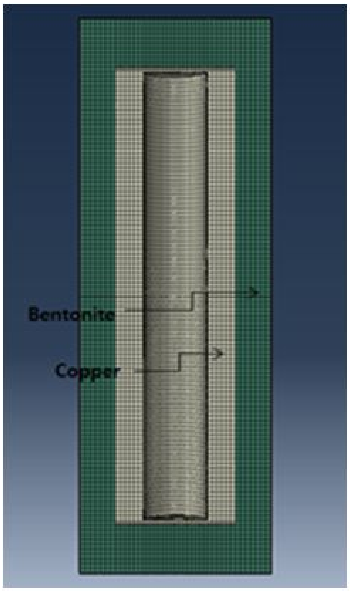
There is the method making a change in the buffer design in order to protect the canister about the shear displacement by the earthquake. The energy which the canister receives on the same shear force is dispersed, or it can reduce by changing the size of the buffer, density, intensity, and etc. [3]. In this paper, the earthquake-resistant performance of the buffer was improved by being the density distribution different.

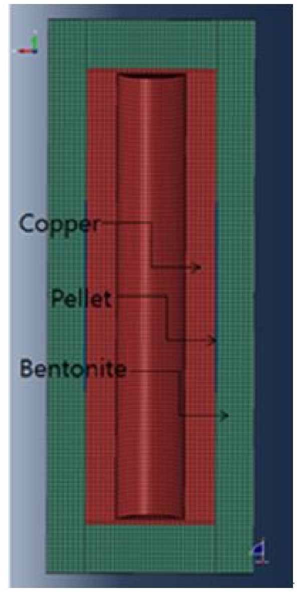
Fig. 8(b) shows the numerical model for the ‘earthquake-resistance buffer’. To improve the earthquake-resistance performance, we designed the buffer by putting the low-density buffer between the canister and buffer, as shown in Fig. 8(b).

Fig 9 shows the result of comparing the earthquake-resistant performance of the earthquake-resistance buffer and the general buffer for the CASE 1. In case of the general buffer, it can be observed that shear displacement increases drastically in the plastic strain about 0.06m . However, because the shear displacement could endure about 0.1m in case of the proposed earthquake-resistance buffer, it could confirm that earthquake-resistant performance of about 66% was improved.

Fig 10 shows the earthquake-resistance performance comparison results between the general buffer and the earthquake-resistance buffer for the CASE 2. When a general buffer is used, the disposal canister is damaged when the shear displacement is 0.04 m. In the case of an earthquake-resistance buffer, the canister is not damaged although it is displaced at about 0.06m. It was that the earthquake-resistance performance of the earthquake-resistance buffer was improved by about 40% in comparison with the general buffer.

Fig 11 shows the earthquake-resistance performance comparison results between the general buffer and the earthquake-resistance buffer for the CASE 2. When a general buffer is used, the disposal canister is damaged when the shear displacement is 0.11 m. In the case of an earthquake-resistance buffer, the canister is not damaged although it is displaced at about 0.18m. It was that the earthquake-resistance performance of the earthquake-resistance buffer was improved by about 64% in comparison with the general buffer.





(a) (b)

Fig. 8 ABAQUS analytic model for (a) the general buffer and (b) the earthquake-resistance buffer.

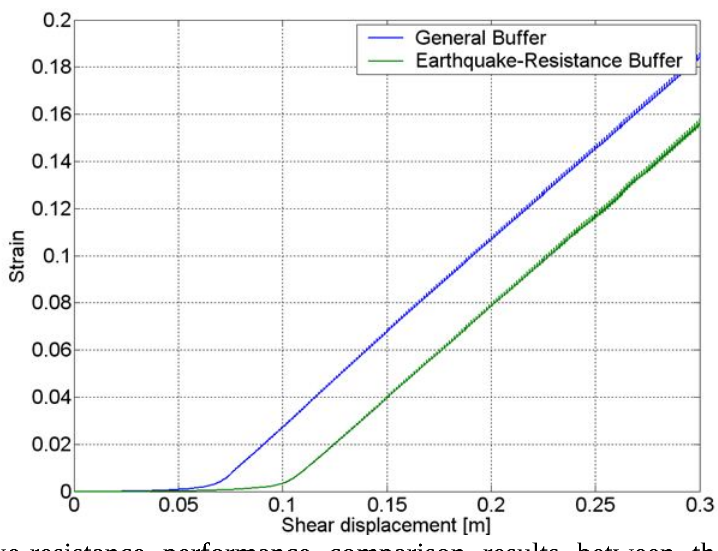


Fig. 9 The earthquake-resistance performance comparison results between the general buffer and earthquake-resistance buffer for the CASE 1.

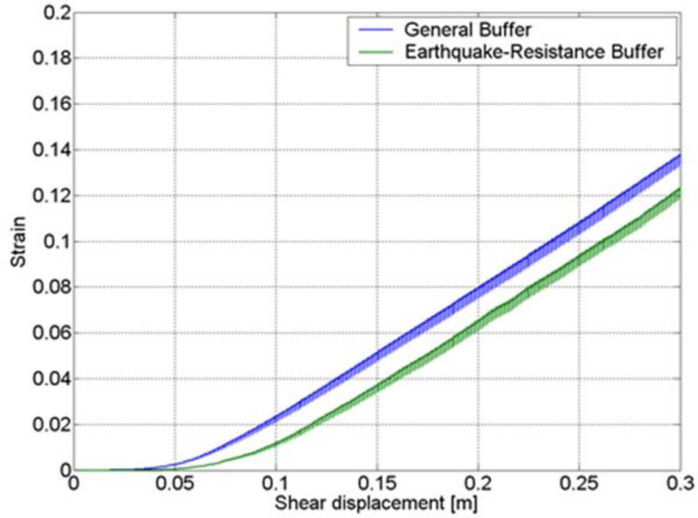


Fig. 10 The earthquake-resistance performance comparison results between the general buffer and earthquake-resistance buffer for the CASE 2.

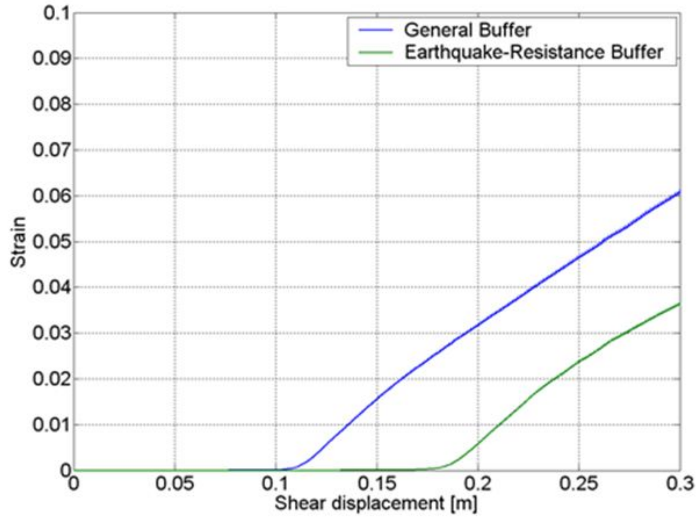


Fig. 11 The earthquake-resistance performance comparison results between the general buffer and earthquake-resistance buffer for the CASE 3.

CONCLUSIONS

The dynamic behavior of the radioactive waste disposal canister was analyzed for a case in which an earthquake was generated. In this case, the disposal canister received the serious damage. In this paper, the earthquake-resistance buffer material was developed in order to prevent this damage. By adding small-density buffer between the canister and buffer, the earthquake-resistant performance was improved about 65%.

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