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Shielding Effectiveness of Concrete Against HEMP in NPPs

Hyunki Kim [*], Chulwoong Son
Korea Hydro & Nuclear Power Co., Central Research Institute 70 Yuseong-daero, Yuseong-gu, Daejeon, 34101, Korea
[*]*Corresponding author: hk49.kim@khnp.co.kr*

1. Introduction

Recently, North Korea's missile provocation has increased EMP threats to social infrastructure in South Korea. EMP is abbreviation of Electromagnetic pulse, which generally causes electronic devices to malfunction or breakdown, and a powerful EMP can severely damage to the grid and infrastructure. But, there are no research cases of EMP effect analysis for the power industry including NPPs (Nuclear Power Plants) in Korea, and the term related to EMP is strange. In this paper, the electromagnetic properties of concrete are analyzed by moisture content, lifetime, wall thickness and loss factor.

2. Shielding Effectiveness Concepts

2.1 Shielding Effectiveness

SE (Shielding Effectiveness) is test that emits electromagnetic waves outside a structure such as a reinforced concrete and measures the degree of attenuation inside the structure. For this test, it is possible to analyze how electromagnetic pulse form HEMP(High-Altitude Electromagnetic Pulse) passed through the structure and affects the internal devices. SE is defined as below in MIL-STD-188-125-1 [1]. PoE (Point of Entry) losses are not considered.

$$\mathrm{SE} = 20 \log_{10} \frac{V_c}{V_m} \quad [\mathrm{dB}] \qquad (1)$$

where V_c and V_m are the strength without structure and with structure, respectively.

According to boundary conditions, EM wave's propagation can be described by Maxwell's equations. It is important to understand dielectric characteristic with relative permittivity ε and relative permeability μ.

The complex relative permittivity, ε* of a material can be expressed as (2). It describes the energy absorption and attenuation within the material [2].

$$\varepsilon^* = \varepsilon' - j\,\varepsilon'' \qquad (2)$$

where ε' *and* ε'' are the dielectric constant and dielectric loss factor, respectively. They can be changed to degree on moisture content and concrete lifetime.

2.2 Reflection Loss

Shielding effectiveness can be defined as the sum of reflection loss, absorption loss and multiple re-reflection loss [4]. By definition, reflection loss in dB is

$$R_{dB} = 20 \log_{10}\left(\left|\frac{\eta_0 + \eta}{4\,\eta\,\eta_0}\right|\right) \qquad (3)$$

where $\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$ and $\eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}}$ are the intrinsic impedances of free space and concrete, respectively [3]. ω is the angular frequency, σ is the conductivity of the material.

2.3 Absorption Loss

The absorption loss is

$$A_{dB} = 20 \log_{10}(|e^{\gamma d}|) \qquad (4)$$

where γ and d are the complex propagation constant and the thickness of the structure, respectively. γ consists of attenuation and phase constants of the medium, can be expressed as $\sqrt{j\omega\mu(\sigma + j\omega\varepsilon)}$.

2.4 Multiple re-Reflection Loss

The multiple re-reflection is

$$M_{dB} = 20 \log_{10}\left(\left|1 - \left(\frac{\eta_0 - \eta}{\eta_0 + \eta}\right)^2 e^{-\gamma d}\right|\right) \qquad (5)$$

Considering (2)-(5), permittivity and permeability of the material of structure are crucial parameters to determine shielding effectiveness.

3. Shielding Effectiveness Analysis of Concrete

3.1 Moisture Content

The reinforced concrete SE is based on the SE by the concrete conductivity and the SE of the reinforced grid. Concrete conductivity is determined by the moisture content. As the moisture content is higher, concrete will offer higher attenuation level. That is, dry concrete has low shielding effectiveness. In the high-frequency region, attenuation characteristic is greater.

Fig. 1 shows the SE characteristics for three different complex permittivity of concrete with the moisture content (0.2%, 5.5% and 12.0%) [5].

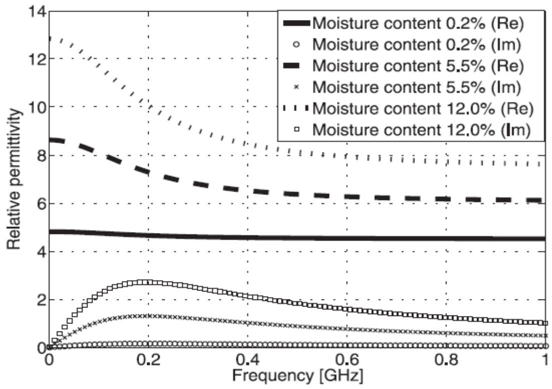

Fig. 1. Complex permittivity of concrete with the moisture constant

3.2 SE by Moisture Content (t=400mm)

Fig. 2 shows the SE characteristics for the thinnest concrete wall (t=400mm) with the moisture content (0.2%, 5.5% and 12.0%). At high-frequency, SE is higher with high moisture content. In particular, the difference between 12.0% and 0.2% is over 8dB at high-frequency.

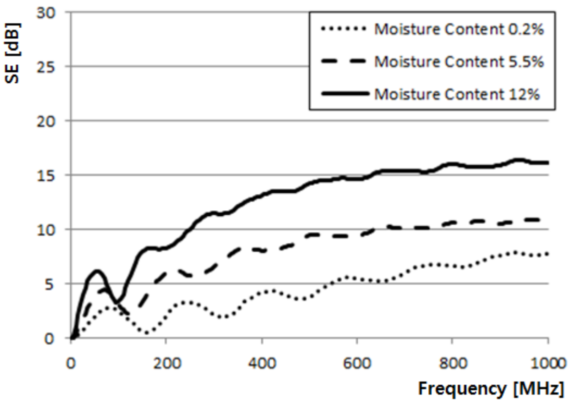

Fig. 2. SE of concrete with the moisture content (t=400mm)

3.3 SE by Moisture Content (t=800mm)

Fig. 3 shows the SE characteristics for the thickest concrete wall (t=800mm) with the moisture content (0.2%, 5.5% and 12.0%). According to Fig. 2 and Fig. 3, the influence of the concrete thickness is dominant in the higher frequency.

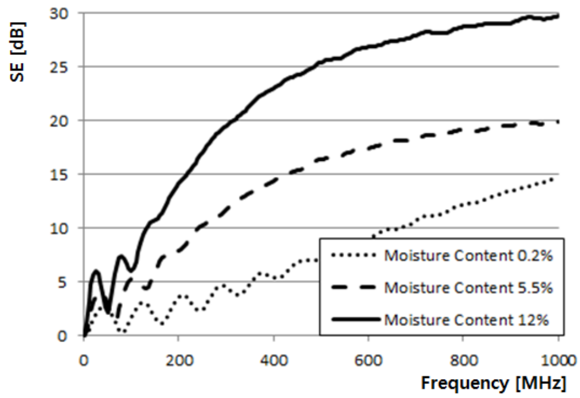

Fig. 3. SE of concrete with the moisture content (t=800mm)

3.4 SE by Loss Tangent

Fig. 4 shows the SE for the concrete with loss tangent. Loss tangent is parameter that indicates the loss due to the material of the dielectric where electric field is transmitted. The complex permittivity imaginary part of the dielectric medium is calculated by real part and defined as tan δ [5]. As it is smaller, loss is lower during the wave propagation.

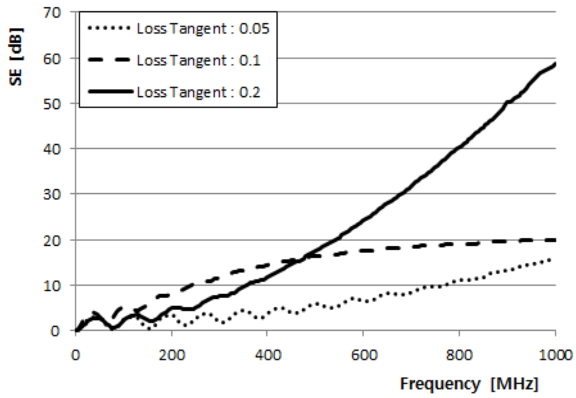

Fig. 4. SE of concrete with loss tangent (0.05, 0.1 and 0.2, where ε = 5)

3.5 SE by Concrete Aging

Fig. 5 shows the SE for the concrete aging with 1 year and 40 year. The airgap of concrete reduces its dielectric constant over time [6]. Eventually, aging of the concrete contribute to lower SE. The permittivity of concrete is referred to CST-MWS's library. And one year and 40 year concrete are compared with considering lifetime of NPPs is over 40 years.

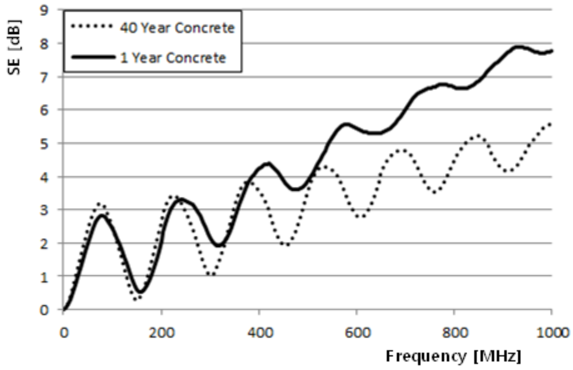

Fig. 5. SE of concrete with aging (1 Year and 40 Year)

4. Conclusions

In this paper, shielding effectiveness of concrete has been considered. Based on the result, it is found that concrete's moisture content increases SE of concrete. It is also found that higher loss tangent contributes more to the SE. It is concluded that concrete offers more attenuation at higher frequencies due to loss tangent, moisture content. In addition, the thick concrete walls have greater SE. However, 40 year old concrete has given a bad shielding performance when compared to the one year concrete, owing to decreasing the permittivity constant.

Overall, permittivity and permeability of the material are crucial parameters to determine the SE of the structure. The results of this paper can be applied to the construction of concrete for protecting HEMP in NPPs.

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