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ANALYSIS & ESTIMATION OF EM ENERGY COUPLING TO THE UNDERGROUND STRUCTURES USING COMPUTATIONAL METHOD

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ABSTRACT

In case of the large underground structures the Electro-Magnetic Compatibility, necessarily susceptibility, with respect to the external electromagnetic sources is very important as the vital equipment used inside these structures are affected due to external sources. Further, the selection of structure material, its shape and size is not governed as per EMC requirements. In this paper the shielding effectiveness of soil, structure and enclosure is computed with respect to the external plane wave source. The levels of E-field & M-field penetration are also computed for various soil conditions. The results have been validated post realization.

KEYWORDS: EMI/EMC, Computational Electro-Magnetic Methods, Shielding, Electro-Magnetic (EM) Energy

The underground structures are widely used in defense applications for storage, command & control centers and survival shelters. The modern underground structures house various electronic equipment like voice-data communication system, controllers used in automation, surveillance systems etc. The EMC of these structures with respect to external sources is very important as it houses many vital electronic systems. Generally, the buried structures are having soil cover having thickness of the order of 1-10 m. The soil cover helps in attenuating the EM energy however attenuation varies with the type of soil. It is well known that the damped soil offers very good attenuation properties (Antonini, 2003). The user most of the time do not have control over the condition of soil. Also, the selection of shape & size of the structure is governed by the other requirements such as static & dynamic loading on the structure, occupancy, and utility therefore it is imperative to analyze various conditions and estimate amount of EM energy coupling to underground structures through penetration and Point of Entries (PoE).EM propagation through Reinforced Cement Concrete (RCC) walls and slabs have been studied and reported in (Chiba, Migazakin, 2003), (Shoory, 2009). However very less work is reported for underground applications as soil interaction with structure modifies the boundary conditions and makes the problem complex. Analytical solution to the problem having non-homogenous multiple layers of soil, structure & different metals is very difficult. Therefore, computational method of Finite Integral Technique with Perfect Boundary Approximation (FIT+PBA) technique using multilevel sub-gridding scheme is used to compute coupling (Paul, 2006). The model of the structure using Reinforced Cement Concrete including reinforcement bars and thin mesh of steel is made using CST Microwave Studio. The EM energy in the form of Electro-Magnetic Pulse of very high amplitude having rise time of the order of 2-10 n sec is used as external disturbance signal. Humidity in the soil changes the electrical properties of the soil therefore simulation have been carried out considering two cases of soil Dry Soil & Wet Soil. Although the rock content in the soil also affects the electrical properties, however it is difficult to model non-homogenous mixture of rocky soil therefore simulation is carried out only for above mentioned two cases.

MODELLING AND ANALYSIS

Problem Formulation

The cylindrical structure having inner diameter of 2.5 m, with 14 mm and 10 mm thick reinforcing bars made up of mild steel, in the form of mesh is considered. The soil cover of 2 m thick on the top of this structure with dry and wet types is considered. This underground structure is subjected to plane wave defined by following equation.

$$E(t) = kE_0\left(e^{-\alpha t} - e^{-\beta t}\right) \quad \text{--- (1)}$$

Where, $\alpha = 4 \times 10^7, \beta = 6 \times 10^8 s^{-1}$

$k = 1.3$, $E_0 = 5 \times 10^4\ V/m$

The computational problem could be defined as for the above defined structure compute the values of E-field & H-filed penetrations through structure and soil thereby compute the required Shielding Effectiveness (SE). The SE, in case is not adequate, suitable solution be suggested.

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Selection of Method

There are various computational methods available to solve the problem defined in section-A such as Finite Element Method (FEM), Finite Difference Time Domain Method (FDTD), Method of Moments (MoM) etc. One direct method of discretization of Maxwell's integral equations known as Finite Integral Technique (FIT) is also widely used (Clemens, 2001). Computational methods are chosen on the basis of tradeoffs between accuracy, speed, storage requirements, and versatility and are geometry dependent. Time domain methods are suitable for wide frequency band analysis. In the case of Cartesian grids, the FIT formulation can be rewritten in time domain to yield standard Finite Difference Time Domain methods (FDTD). However, whereas classical FDTD methods are limited to staircase approximations of complex boundaries, the Perfect Boundary Approximation technique applied to the FIT algorithm maintains all the advantages of structured Cartesian grids, while allowing an accurate modeling of curved boundaries. This numerical method provides a universal spatial discretization scheme, applicable to various electromagnetic problems, ranging from static field calculations to high frequency applications in time or frequency domain. For the problem under consideration time domain solver based on FIT & PBA used to compute penetration of the fields inside the structure.

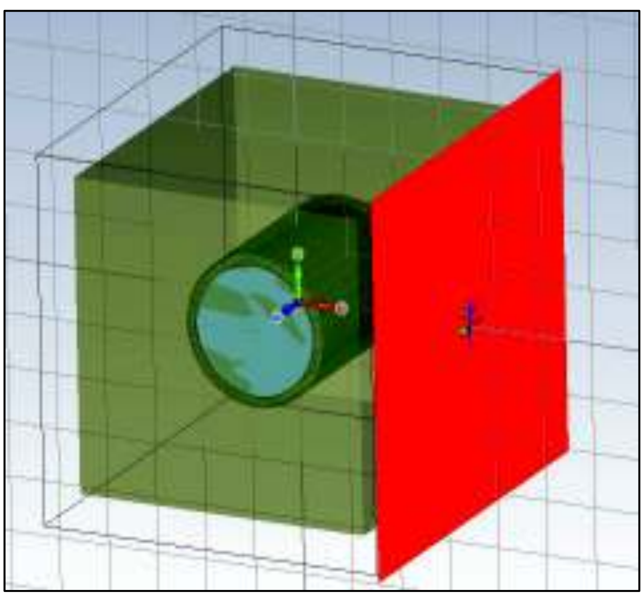

Figure 1: Model of the cylindrical structure with soil cover

SIMULATION RESULTS

The model using CST Microwave Studio software for cylindrical shaped structure with reinforcing mild steel bars is made. Actual cylindrical structure is electrically very long which is highly difficult to model & simulate using EM software due to memory requirement and speed of processor. Therefore, 4m long one module of concrete is used for simulation. The soil properties selected are mentioned in Table,1. Two types of the soil are considered for the analysis, sandy wet and sandy-dry soil. The simulation is carried out for both the vertical as well as horizontal polarization. The simulation results are shown through figure 2 to 8. The penetrated E-field and H-field, inside the concrete module, are plotted against Time (μSec) as shown in fig. 2 & 3.

Table 1: Properties of soil

Parameter	Dry soil	Wet Soil
μ_r	1.00	1.00
ε_r	2.53	13.0
Loss Tangent	0.0036	0.29
Density	1550 kg/m^3	1800 kg/m^3

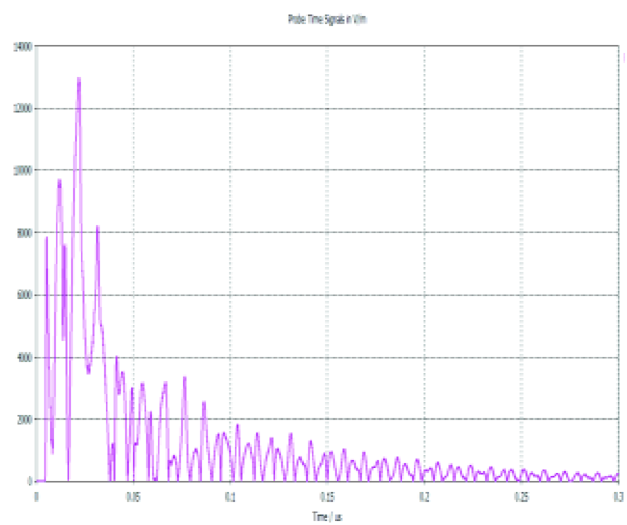

Figure 2: Plot of E-field against Time (μSec) inside the concrete module with soil

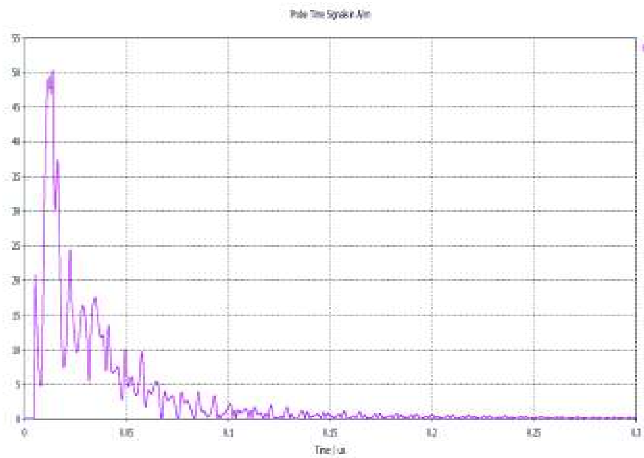

Figure 3: Plot of H-field against Time(μSec) inside the concrete module with soil

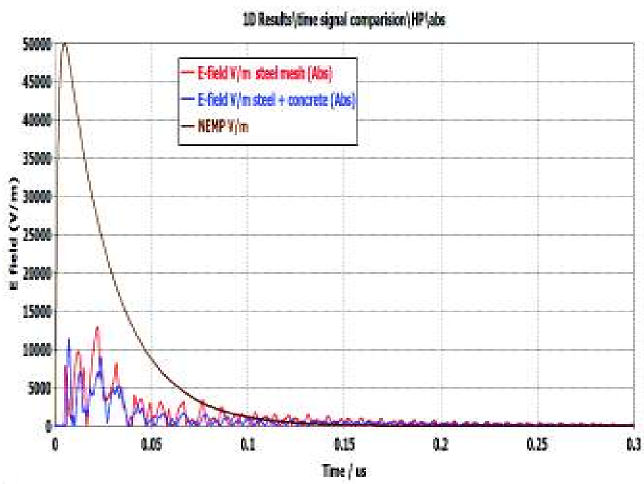

Figure 4: Plot of Electromagnetic pulse applied, E-field with steel mesh, and E-field with steel mesh + concrete vs Time (μSec)

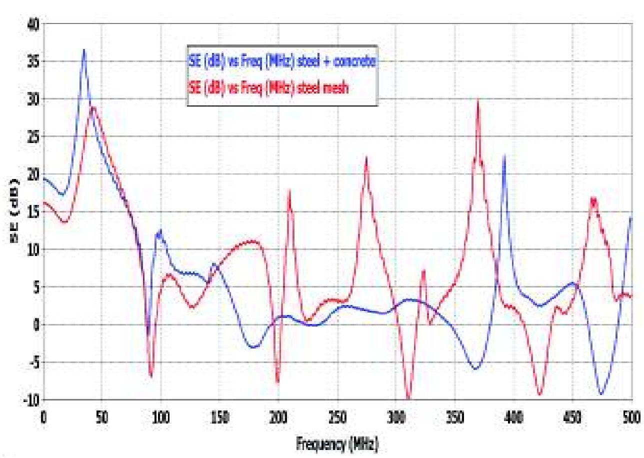

Figure 5: Plot of SE (dB) vs frequency (MHz) for only steel mesh & steel + concrete module

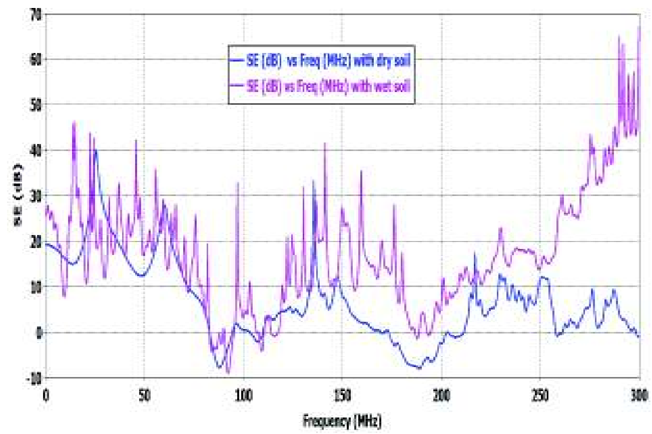

Figure 6: Plot of SE (dB) for concrete module along with dry & wet soil vs. Frequency (MHz)

The simulation is carried out in stages to understand and quantify the effect of mild steel mesh used in concrete, type of soil and concrete layer. These results are useful for approximate guess of similar structure.

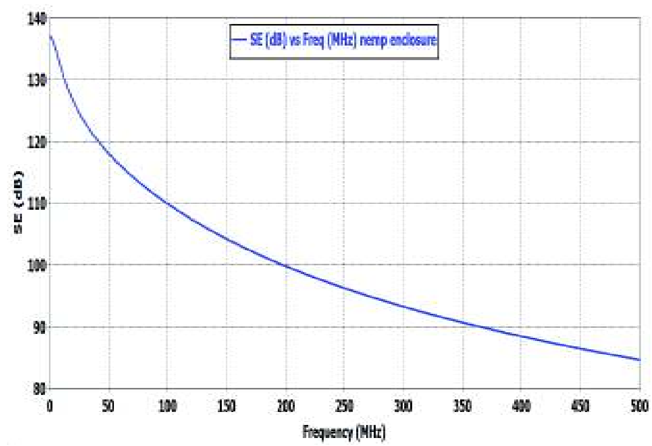

Figure 7: Plot of SE (dB) vs frequency (MHz) for metallic enclosure

The simulation was carried out in stages viz. (i) steel mesh with reinforcing, (ii) steel mesh along with concrete layer of 200 mm. (iii) concrete module with soil cover, (iv) only soil cover, (v) metallic enclosure. The equipment housed in the underground structure shall have minimum of 80 dB SE for E-field and 60 dB SE for M-field over the frequency range of 100 kHz-1 GHz as per Mil-Std-461F. However, simulation results shows that with soil cover, concrete module can provide peak SE approximately 30 dB which is not adequate. The higher SE can be achieved using metallic cabinets of the equipment housed inside the structure. This requires multiple such cabinets to cover all the equipment. Further the radiated energy propagated inside the structure can couple with the cables and shall lead to conduction. To avoid these difficulties a single metallic enclosure having better shielding for electric and magnetic field over the specified frequency range is suggested. The dimensions of this enclosure are selected so that all the equipment can be housed.

The metallic enclosure has layers of aluminum 1.4 mm, mild steel of 2.5 mm, polyurethane foam of 45 mm and aluminum layer of 1.4 mm. The enclosure has circular openings for ventilation. Computationally enclosure with two circular openings offered SE more than 80 dB over the 10 kHz to 1 GHz frequency range. The enclosure is realized and tested for SE as per Mil Std-188-125-1 & RS-105 of Mil-Std-461F. The measured SE of the enclosure is more than 80 dB for E-field and found to be close to that of computed values.

The total preprocessing & post processing simulation time required was 28.44 hrs. on 16 core 2.7 GHz, Xeon workstation with 32 GB RAM.

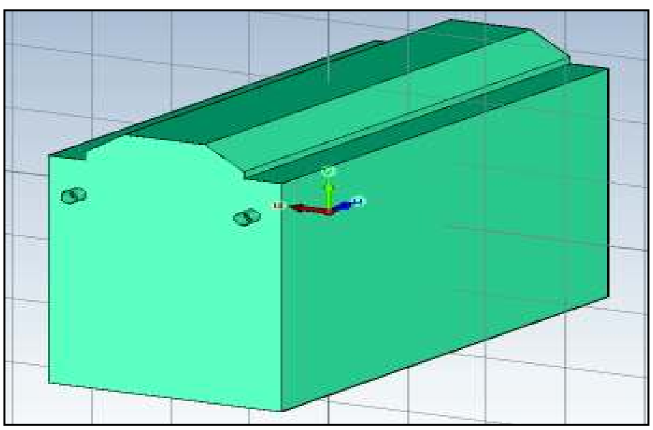

Figure 7: Model of the metallic enclosure

CONCLUSION

In this paper the practical problem of EMC of the underground structures is addressed. The simulation results indicate that there is need of additional shielding to raise the level of shielding effectiveness of the equipment inside the underground structure. The metallic enclosure is designed and tested. The simulation results are useful for similar applications.

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