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An experience in the design, implementation and testing of concrete encased grounding electrode for a residential building

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Abstract: *The use of reinforced concrete in buildings foundation as a ground electrode is not a new idea and has been common since the late 1960s. However, the number of available papers and technical reports that detail the implementation of that, and provide practical results for real case studies is not too many. The purpose of this paper is to describe the experiences gained from the design, implementation and field testing of a relatively large residential building's concrete encased grounding electrode and to investigate if this electrode is able to meet the expectations of different aspects of a ground electrode. The paper shows methodology and all levels of testing for qualifying a real concrete encased grounding system in a typical large residential building, and can be considered as a pattern for similar cases, especially that concrete encased grounding system is not well known in Iran compared to American or European countries.*
Key Words*: Concrete encased grounding electrode, resistivity, Equipotential bonding, NEC, UFER*

I.INTRODUCTION

Section 250.50 of NEC emphasizes the need for all ground electrodes in one place to be bounded to form a "ground system". This requirement includes all electrodes buried in concrete, which is also present in the building or structure. There is one exception, and that is in buildings and structures where electrodes buried in concrete, to the ground system, may damage the structural integrity of the building, or adversely affect existing structures (such as corrosion). The foundations implementation, it is one of the first stages of a construction project, but the implementation of electrical installations is traditionally one of its final stages. Then, a good coordination between electrical and structural engineers. In the early stages of reinforcement, they must make sure that the rebars are properly connected and properly bonded to form a concrete encased grounding electrode (CEGE).

The invention of CEGE owes much to the frost and perspicuity of Herbert G. Ufer. As a vice president at Underwriters Laboratories, he assisted the U.S. military to solve problems of installations grounding in Arizona military buildings. Ufer's findings in the 1940s proved the effectiveness of CEGE. The Army needed electrodes with a resistance of 5 ohms or less for lightning arresters installed in ammunition and explosives dumps at the Navajo Ordnance Depot in Flagstaff and Davis-Monthan Air Force Base in Tucson. Implementing such an electrode with conventional methods (such as rod or belt electrodes, etc.) was very expensive. Ufer developed a prototype for a CEGE that used 20-inch reinforcing bars in the structure, up to 20 feet long and located 2 feet deep in the ammunition depot foundation.

Measurement of resistance over a 20-year period showed stable values of 2 to 5 ohms for the resistance of these electrodes, which well met the expectations of the US Army at the time. The results of this study eventually led to what the NEC today recognizes as CEGE.

Since then, through repeated and numerous experiences, CGEG has been proven to perform well and have a good life. The foundation rebars of any building will usually exist as long as the building is standing. Since usually all the rebars in the building foundation environment are connected by reinforcement wires, it acts as a ring electrode, although the contact surface of such an electrode is much higher than a normal ring (for example, a wire). The base of the columns is also located on the perimeter of the foundation, so they, in turn, lead to significant ground contact. Concrete, while retaining its moisture over time, constantly absorbs natural ground moisture through the base floor of the columns. This creates an effective connection between the CGEG and the ground. The foundation of a building is typically the largest ground electrode in any structure.

In 1978, NEC allowed the 1/2-inch rebar to be used as a ground electrode. Today, NEC does not use the name Ufer electrode for this type of ground system, calling it the "Concrete Encased Grounding Electrode" or in short "Concrete Encased Electrode (CEE)". In fact, in recent years, the term CEE has been applied to the use of any concrete encased conductor, whether or not similar to the original design given by H. G. Ufer. [3]

For buildings located in an area with high soil resistivity, it is strongly recommended to use CEGE [4]. The Basic version of the Ufer method, only has two main components: concrete and rebar [5]. Previous research shows that the combination of bentonite and concrete can optimize 30% of the results of this method [6,7].

CEGE has also been used to improve the performance of the ground system in the lightning protection system (LPS). The low electrical resistance obtained from this method has led to its use, alone but with certain conditions, to be approved as the ground terminal of LPS. Research has also been conducted to investigate transient states in this type of electrode [8].

The aim of this paper is to express the experiences of field testing of a relatively large CEGE. The purpose of writing this article is not to present a kind of innovation and novelty in this field, but the purpose is to present the process of designing, implementing and finally confirming the quality of a ground electrode buried in a real foundation using various measurement techniques and expressing existing challenges and discussing the results.

II. DESCRIPTION OF THE SITE SPECIFICATIONS

The site is an almost commercial building located in the west of Isfahan (a province in the center of Iran). Its geographical location is shown in Figure 1 and environmental conditions are listed in Table 1.

Figure no 1: The building location and Measurements Direction (Courtesy of Google MAP)

Table no 1: The Site Specifications.

Name of the project		Shahidan complex
Builder		Isfahan Motion of Housing Company
Geographical coordinates	Longitude	51.63052278 E
	Latitude	32. 67798307 N
	Height	1578m
Date of measurement		2022.5.22
Measurement time		8:30 -11:30 AM
Temperature		5-15 ºC
Relative humidity		%37-%52
Last rainy date		More than 10 days ago
Date of measurement		2022.5.22
Measurement time		8:30 -11:30 AM
Temperature		5-15 ºC
Relative humidity		%37-%52
Last rainy date		More than 10 days ago
Date of measurement		2022.5.22
Measurement time		8:30 -11:30 AM

III.DESIGN TIPS

If the reinforced concrete of the building foundation is to be used as a CEGE, the following conditions must be met:

- Insulation is not done between the foundation and the surrounding ground for the purposes such as waterproofing etc. and the concrete of the foundation should be in direct and complete contact with the soil.
- If rebar is used as a buried conductor in concrete, its diameter must be at least 14 mm and if copper wire is used, its cross section should be at least 25 mm^2.
- The reinforcing bars or bare copper conductor must be encased by at least 5 cm of the final concrete surface.
- The foundation final floor mats be at the level of at least -80 cm from the ground.
- The conductor enclosed in the concrete of the foundation must be at least 6 meters long.
- The conductor exit point from the concrete should be covered with insulating material to prevent corrosion.
- The combination of the main equipotential bonding of the reinforced foundation and CEGE is possible, if the requirements of both are met simultaneously.

At the above mentioned site, first, design procedure was done and 14mm rebars as conductors, and concrete basements in all foundations were applied as shown in Figures 2 and 3. All connections were made by welding method and 2 outgoing points from CEGE were considered for the main ground terminal (MET). Figure 4 shows other details. In order to deal with electromagnetic compatibility, a conductor was embedded around the reinforced concrete foundation in such a way that the dimensions of each meshes of it is not be more than 20m*20m. It should be noted that the risk assessment based on the

IEC62305-2 standard for considered building showed that no LPS is required.

Figure no 2: Rebars used for implementing CEGE

IV.TEST RESULTS

The selected path for measurement was shown in Figure 1. This direction was easy to access and safe for inserting the test spikes and injecting current. Also, there was no noise and stray voltages in it. Therefore, all tests were performed in that. The measurement results for the various tests are listed in the following (Detail of the tests procedures are explained in [9] and [10] and do not need to be repeated here). To confirm the accuracy of the results, the amount of contact resistance of the test spikes is noted in all measurements. The values for the electrode resistance are in ohms, the contact resistances of the spikes are in kilo-ohms, and the resistivity values are in ohmmeters. Figure 7 shows the fall of potential curve and the presence of an approximately smooth part in it. As a computational assessment for CEGE resistance, it can be calculated by:

$$R = \frac{0.2\,\rho}{\sqrt[3]{V}} \qquad (1)$$

Here, ρ is the average soil resistivity in the CEGE level and V is the total volume of reinforced concrete used as CEGE. Then, with the specific values of this project:

$$R = \frac{0.2*30}{\sqrt[3]{2200}} = 0.46 \qquad (2)$$

The results of the measurements and calculation are summarized as Table 7.

Figure no 3: Rebars used for implementing CEGE

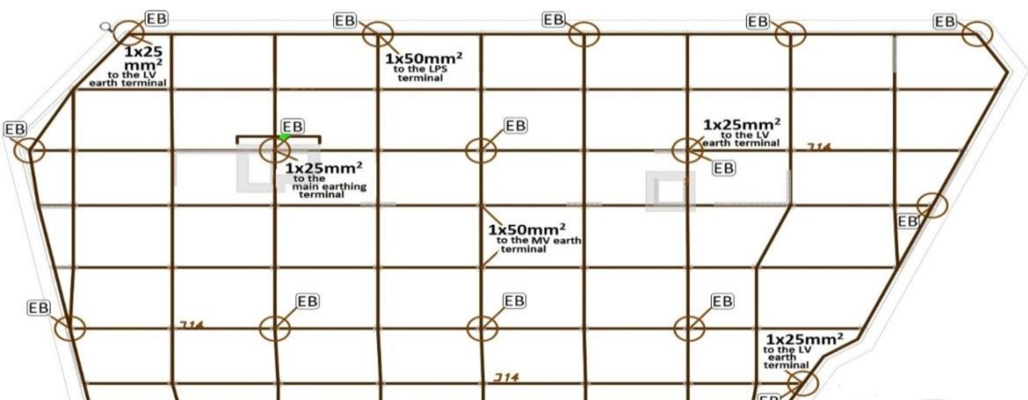

Figure no 4: Detail of the designed CEGE

Table no 2: Results of the slope method (The first step)

% of distance between electrode and current spike	Resistances (Ω)	Current spike contact resistance (kΩ)	Voltage spike contact resistance (kΩ)
60	0.41	0.1	0.2
40	0.35	0.1	0.3
20	0.26	0.1	0.2

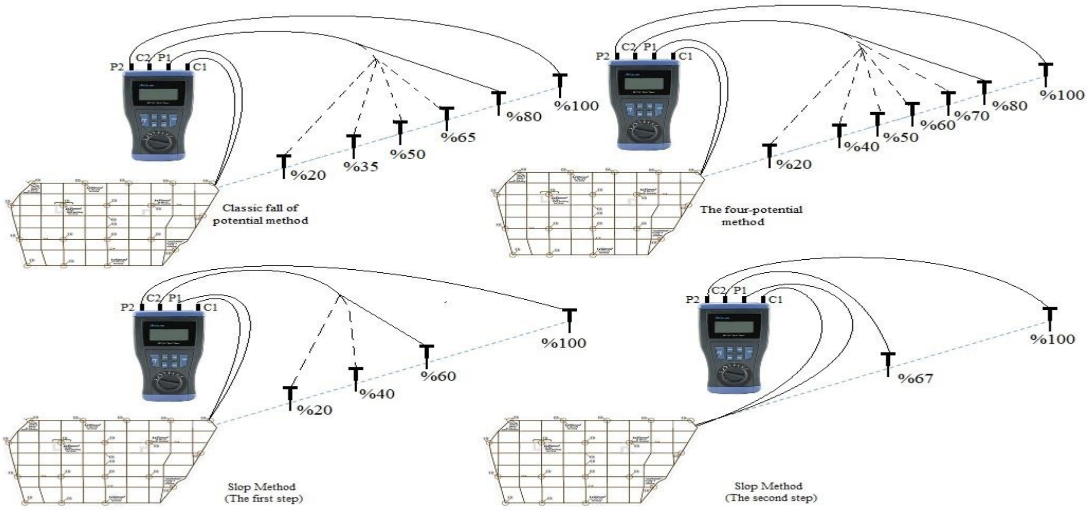

Figure no 5: The methods used for measuring CEGE resistance

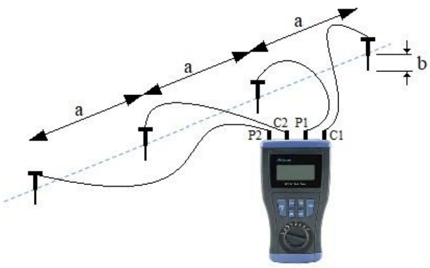

Figure no 6: Wenner method used for measuring soil resistivity

Table no 3: Results of the slope method (The second step)

% of distance between electrode and current spike	Resistances (Ω)	Current spike contact resistance (kΩ)	Voltage spike contact resistance (kΩ)
67	0.35	0.1	0.25

Table no 4 : Results of the four potential method

% of distance between electrode and current spike	Resistances (Ω)	Current spike contact resistance (kΩ)	Voltage spike contact resistance (kΩ)
80	0.62	0.1	0.2
70	0.43	0.1	0.1
60	0.41	0.1	0.2
50	0.4	0.1	0.1
40	0.35	0.1	0.3
20	0.26	0.1	0.4

Table no 5: Results of the classical fall of potential method

% of distance between electrode and current spike	Resistances (Ω)	Current spike contact resistance (kΩ)	Voltage spike contact resistance (kΩ)
80	0.71	0.1	0.2
65	0.47	0.1	0.1
50	0.45	0.1	0.1
35	0.4	0.1	0.5
20	0.26	0.1	0.4

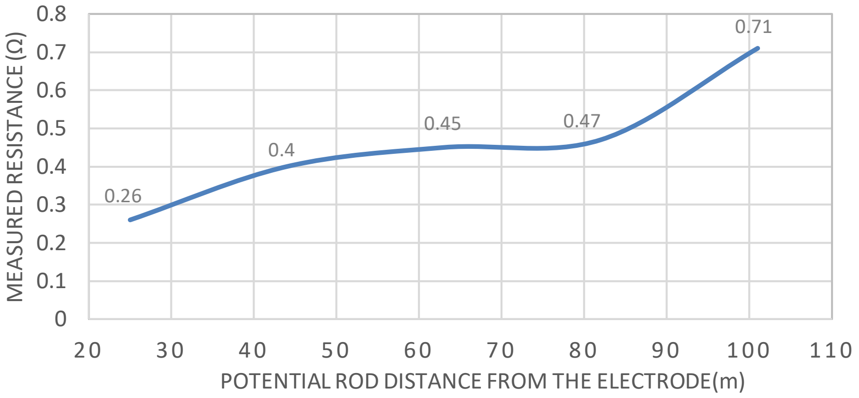

Figure no 7: Resistance-Distance curve (fall of potential curve)

Table no 6: Results of the Wenner method

Distance between the adjacent spikes (m)	Current spike contact resistance (kΩ)	Voltage spike contact resistance (kΩ)	Resistivity (Ω.m)
32.9	1.9	0.6	9
27.8	1.7	1.6	6
37.3	1.3	1	3

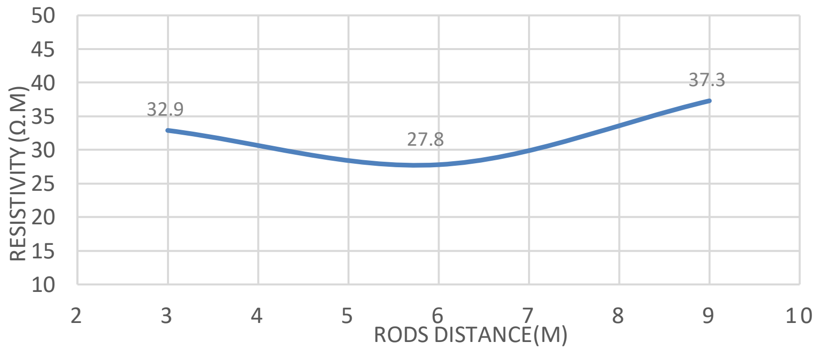

Figure no 8: Soil resistivity profile

Table no 7: Results of the classical fall of potential method

Distance between the adjacent spikes (m)	Classic fall of potential method	Slope method	The four-potential method	Calculation
Electrode resistance (Ω)	0.46	0.35	0.45	0.43
Average value (Ω)	0.46			
% of error to average	%9.5	% -17	%7	%2

V.CONCLUSION

Final conclusion of the test results can be demonstrated as follow:

A. The results are reasonably analogous to the theoretical calculations. In addition, the almost similar results of three different tests show the accuracy of the measurements.

B. The studies show that implemented CEGE is compatible with NFPA 70. The resistance is less than 0.5 ohm, which is very desirable and reliable.

C. The implemented CEGE can be used as a multi-purpose ground electrode, fully compatible with the article 13 of the Iranian National Building Regulations. In other words, it can be used as a protective, safety, and functional ground electrode, in accordance with IEC60364.

D. The implemented CEGE can be used as a common MV/LV ground in the building substation, in accordance with IEC60364.

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