A Study of Onshore Wind Turbine Foundation for Varying Heights in Zone-IV.

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Abstract- Every day, new methods are being created to produce power using renewable energy. Similar to solar, wind, hydro, and nuclear energy. This paper examines the fundamental behaviour, analysis, and design of on-shore wind turbines used to generate renewable energy. It has the top five windiest cities in Gujarat, including Bhuj, Okha, Porbandar, Mundra, and Jamnagar. The primary objective of this master's thesis is to investigate and assess several types of foundation techniques for on-shore (on-land) wind turbines. The thesis would address both geotechnical and structural design, and it will be created in compliance with IS code, an Indian standard. We'll compare the various foundation kinds in terms of their behaviour, functionality, and other elements. In Gujrat state, a wind turbine 130 meters tall is installed on a variety of soil types. The study of the design, analysis, and behaviour of spread foundations and pile raft foundations using various types of piles is presented in this thesis. The Finite Element Method, ARCGIS, and PLAXIS-2D/3D Software are used to comprehend structural mechanics, structural and geotechnical design.

Key Words: **Renewable energy, Indian standards, i.e. IS code, geotechnical and structural design, basic behavior, analysis of on-shore type of Wind Turbines, behaviors, functionality, and other factors, 130m tall wind turbine , various types of Soil conditions, spread foundation and pile raft foundation, Finite Element Method, ARCGIS software, PLAXIS-2D/3D Software.**

1. INTRODUCTION

The supply of coal, oil, natural gas, and other conventional energy sources is limited, and if they were to exhaust at the rate at which they are already being used, they would do so within a few decades. Living without energy, or more precisely without electrical energy, is quite challenging given the growth of society and our modern way of life. What might the answer to this be? Everyone agreed that the only option was to consider renewable or non-delectable sources of energy. Solar, wind, biomass, tidal, geothermal, ocean thermal, etc. are the main sources of renewable energy (RE), according to the list.

Conventional methods of producing power by burning coal, oil, and natural gas are swiftly depleting their supply of resources. Energy famine is quite likely to occur in several places in the near future.

To meet the growing need for electricity in a sustainable manner, wind energy is acknowledged as one of the most cutting-edge, cost – effective, and tried renewable energy alternative.

Despite the fact that onshore wind energy technology has advance to the point of large-scale deployment and has become competitive with fossil fuel- based electricity generation, with supportive policy regimes around the world, offshore wind energy development has not yet reached the same level of exploitation as onshore wind energy.

ReNew Power Ventures, Suzlon, Tata Power Solar Systems Ltd., Indian Biogas Association, Amplus Solar, Shell, Hindustan Power, Adani Renewables that's are the company in India.

1.1 Wind Turbine

The term Wind Turbine is now used widely to describe machinery with rotating blades that capture wind kinetic energy and convert it to usable electrical energy.

Wind turbine are used in several countries to reduce energy prices and rely less on fossils fuels. They represent a large Source of erratic renewable energy.

Charles F Brush invented the first wind turbine that generated electricity in 1888.

With very few exceptions, wind turbine do not release pollutants into the atmosphere or require water for cooling. Additionally, the usage of fossil fuels to produce energy be reduce thanks to wind turbine, which would reduce total air pollution and carbon dioxide emissions.

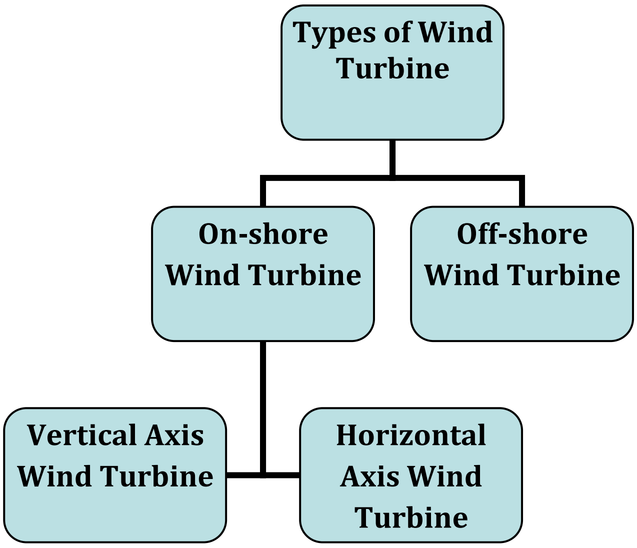
In 1986, Tamil Nadu, Gujrat, and Maharashtra's coastal regions saw the construction of Indies first wind farms, which included 55Kw vistas wind turbines. The capacity has significantly increased during the last five years.

The 140-m tallest wind turbine in India was built in the Jamnagar district by SUZLON.

(Fig:-1.1 India's tallest wind turbine)

1.1.1 Types of Wind Turbine

Wind turbine are categorized based on how they are orientated along their axis. The site's energy needs can be taken into consideration when determining the turbine's power output, which will also have an effect on the turbine's overall size. The axis can be orientated either vertically or horizontally, and each has a different impact on how the complete structure is designed.



- **On-shore Wind Turbine: -** Onshore wind turbines, as opposed to offshore ones, are those that are on land. Most frequently, they are found in areas with little population density and poor conservation valve.

(Fig:-1.2 On-shore type of wind turbine)

- **Off-shore Wind Turbine: -** Off- shore wind farms are ones that are erected in a body of water, usually close to the shore. Off- shore wind farms are chosen because they produce more energy and can get strong, consistent wind above bodies of water.

(Fig:-1.3 Off-shore type of wind turbine)

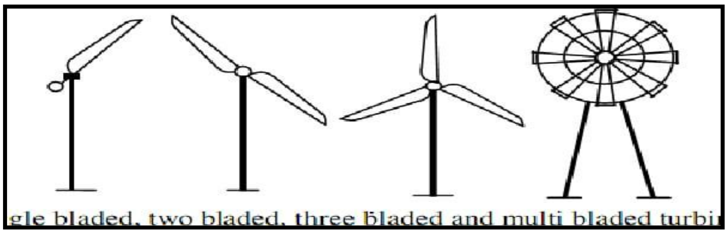
1.1.1.1 Types of On-Shore Wind Turbine

The classification of wind turbines is based on the direction of their axis. The axis can be orientated either vertically or horizontally, and each has a unique effect on how the entire construction is built.

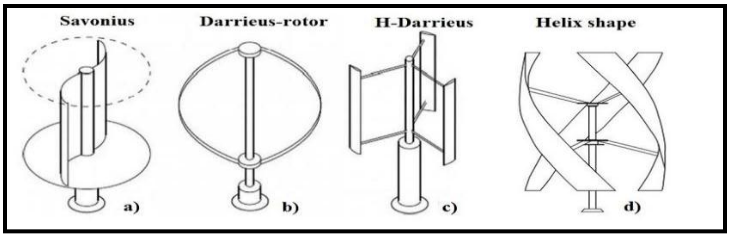
The two primary types of wind turbines are horizontal axis wind turbines (HAWT) and Vertical axis wind turbine (VAWT), both of which are showed in fig below.

The more popular and widespread wind turbines for producing power are those with a horizontal axis. These reasons and the fact that there is greater knowledge about the building of horizontal axis wind turbines.

Only the horizontal axis wind turbine (HAWT) types is used in this study's analysis and foundation design.

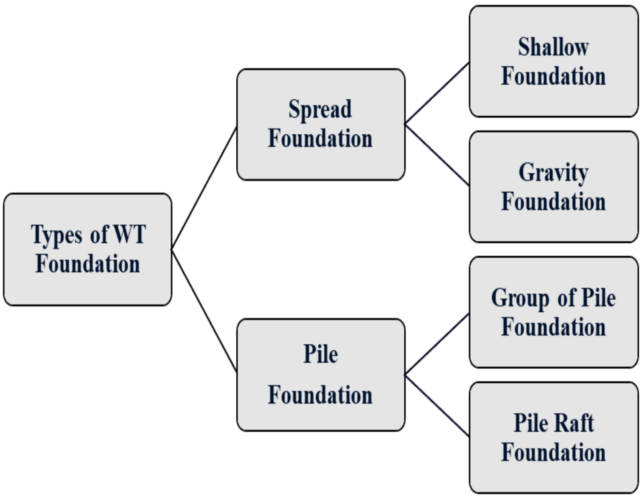


(Fig-1.4 Horizontal axis Wind Turbine HAWT)

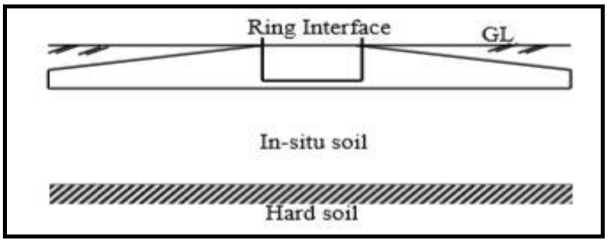


(Fig-1.5 Vertical axis Wind Turbine VAWT)

1.2 On-shore types of Wind Turbine Foundation:-



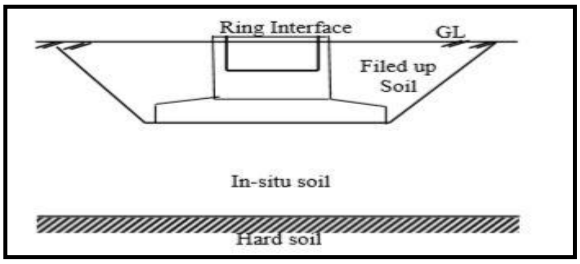
1. **Shallow Foundation: -** Shallow foundation is one of the different types of spread footing. Those with a shallow foundation are those that are dispersed on or just below the ground. Fig:-1.6. The base area of the shallow foundation is sufficiently large to prevent topple of the wind turbine tower. The narrow shallow foundation is designed to keep the footing's center at base level close to the effects of all forces. This can be achieved by providing a sturdy, sustainable structure because it is easy to build, requires minimal excavation, and can be filled in quickly.



(Fig:-1.6 Shallow foundation on the ground)

2. **Gravity Foundation: -** The gravity foundation is one type of spread foundation that is positioned below the surface of the ground by digging the soil after construction. The excavated area is then either filled with the same soil or a different type of soil, depending on the project (Fig:-1.7). For better sustainability, it is always recommended to construct the gravity foundation of a wind turbine tower on a film soil layer rather than on weak or soft soils. Sustainability will be provided by the weight of the filler dirt positioned above the footing base. As a result of the gravity footing being buried to a certain depth in the soil, the stability provided by the filler earth placed above the footing foundation will prevent the building from toppling. Having fewer overturns and it

- Provides sustainability by using less concrete for the gravity footing and less overturning. The drawback of this form of foundation is the need for excavation and re-filling.

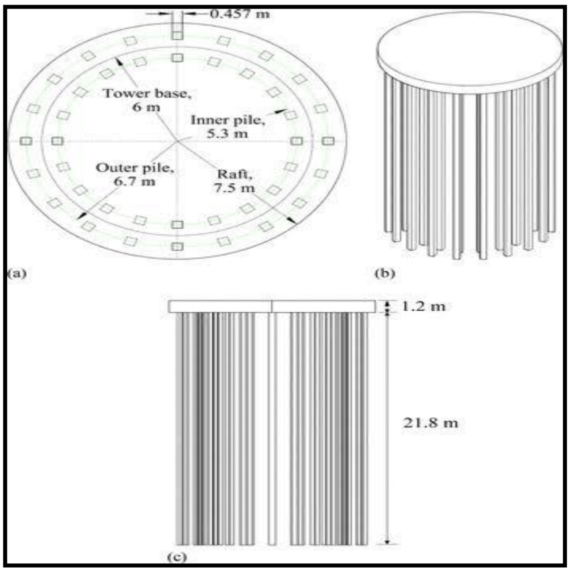


(Fig:-1.7 Gravity type Foundation)

1. **Group of Pile Foundation: -** Depending on the geological structures, the bed rock may occasionally be found at a relatively shallow depth. For greater wind turbine tower sustainability in such circumstances, the pile can be driven or positioned at such bedrock formation levels. Since pile deformations, rather than soil compression at pile tip level, will be the main cause of settlement, it will be maintained to a minimum. In this case, it is believed that the dirt won't add any weight.

(Fig:-1.8 Group of Pile Foundation)

2. **Pile- Raft Foundation: -** The combination of spread foundation and a number of piles is known as a "pile raft foundation." Loads can be distributed equally over the top layer of soil by using a spread foundation, and the foundation's pile will carry heavy lords to greater depths. In order to ensure that spread foundations and piling groups are completely surrounded by soil and can support their intended loads, there must be no space between them. In conditions of hard soil and bedrock, gaps between piles and the soil or rock render them useless and lower shaft friction stress. The required number of piles and their depth of termination are determined using the equal settling concept and pile group capacity. To build pile rafts, it is better to use software that is based on the Finite Element Method. The stiffness of the raft and the pile is crucial for modelling the stacked raft analysis.



(Fig:-1.13 Pile Raft Foundation

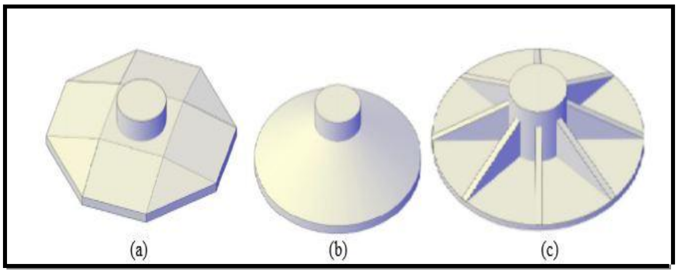
2. LITRATURE REWIEW

1. Ntambakwa, E., Yu, H., Guzman, C., & Rogers, M. (2016, February). Geotechnical design considerations for onshore wind turbine shallow foundations. In Geotechnical and Structural Engineering Congress 2016 (pp. 1153-1165)

This paper presents a discussion of important considerations for geotechnical investigations and design for utility scale wind turbine shallow foundations including global stability, bearing capacity, differential settlement, rotational stiffness and cyclic degradation considerations.

The paper includes detailed discussion of geotechnical design requirements and design approaches which can be utilized to optimize geotechnical aspects of wind turbine foundations. Merits and limitations of typical approaches such as allowable stress design compared to limit state design for bearing capacity will be discussed.

Due to their simplicity, gravity base or spread foundations are one of the chosen foundations for utility-scale onshore wind turbines. Gravity base foundations typically consist of a cylindrical pedestal fixed onto a sizable, octagonal- or circular-shaped base of reinforced concrete. Typical spread or mat foundation widths range from 15 to 20 metres, with a central pedestal that is 4.5 to 5.5 metres in diameter used to connect the foundation to the tower. The foundations normally range in thickness from 2 to 3 metres in the centre, tapering to 1.0 metres or less at the periphery. Figure 2.1 depicts the general layouts of typical shallow spread/mat foundations for wind turbines.



(Fig 2.1: Typical Wind Turbine Foundation Configurations: (a) Octagonal; (b) Circular; (c) Circular modular/segmented)

Normally, the foundation bases are supported between 1 and 3 metres below finished ground elevation, and they are then backfilled with a specific material. For stability against the loads transferred from the turbine tower, this sort of foundation principally relies on massive self-weight and soil overburden/backfill.

This study discusses crucial factors to take into account while designing utility-scale wind turbine spread foundations, geotechnical investigations, and geological risks assessments. According to the American Wind Energy Association, the capital expenditures for typical utility-scale wind generating projects consist of roughly 30% construction costs. High economic losses could occur from unsatisfactory operating performance or failure of wind turbine foundations caused by geotechnical flaws, which are easily avoidable with a well-executed geotechnical design.

In order to complete the engineering design process and supply the essential geotechnical qualities for detailed design of the foundation for each individual turbine position, a thorough geotechnical site study is needed. The following in-situ and laboratory tests are frequently employed in geotechnical analyses of onshore wind turbine foundations

1. Soil Borings
2. Cone Penetration Testing
3. Geophysical Surveys
4. In-Situ Measurements
5. Groundwater Measurements
6. Laboratory Testing

The soil characteristics present at the proposed turbine location have a significant impact on the choice and construction of a wind turbine foundation. When the soil layers at shallow depths demonstrate adequate strength and deformation ability to resist the loads transferred from the turbine tower, a concrete gravity foundation is often preferred.

A thorough subsurface investigation yields accurate geotechnical parameter values for the design of shallow foundations, including the measurement of the base of the foundation, the depth at which it is embedded, the soil unit weight that can be achieved for the backfill, and spring constants (subgrade modulus) for the design of the structure. The geotechnical metrics would also be utilised to assess crucial foundation design criteria, as is mentioned below.

1. Minimum Foundation Stiffness
2. Soil Bearing Capacity
3. Allowable Settlement/Differential Settlement
4. Allowable foundation uplift/gapping
5. Durability
6. Limit State Design Considerations
7. Load and Geotechnical Resistance Factors

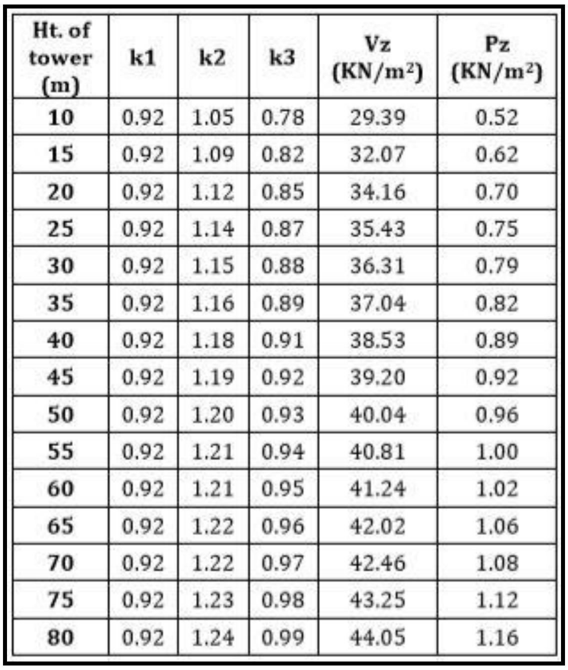
2. Vanathai, R., & Kaviya, T. (2021). Analysis and Design of Onshore Wind Turbine Foundation at Kayathar, Tuticorin District.

WIND and SOLAR are two of the main branches of renewable energy. A significant part of Tamil Nadu's wind energy generation occurs near Kayathar in the Tuticorin District. The current research attempts to demonstrate how wind and earthquake loads affect the foundation of a windmill while taking hard, medium, and soft soil strata into consideration.

The finite element modelling approach was used to model the windmill tower with computer software. This study examines the effects of wind and earthquake pressures as well as checks for bending stress, base shear comparisons, stability, and safety of the foundation of a windmill for hard, medium, and soft soil strata at Kayathar, Tuticorin District.

From zero at ground level to a height known as the gradient height, the wind speed in the atmospheric boundary layer rises with height. The wind load is a significant influencing factor for the windmill because it is higher in height and typically located on open terrain. The combined action of external and internal pressure on the structure determined this effect of wind on it as a hole.

Utilizing IS-875 (Part-3) code, the Wind analysis was carried out. According to code, wind speed at the suggested site was 39 m/s. The structure's high height causes the wind speeds to also increase. Therefore, the Windmill experienced a stronger impact.



Ht. of tower (m)	k1	k2	k3	Vz (KN/m^2)	Pz (KN/m^2)
10	0.92	1.05	0.78	29.39	0.52
15	0.92	1.09	0.82	32.07	0.62
20	0.92	1.12	0.85	34.16	0.70
25	0.92	1.14	0.87	35.43	0.75
30	0.92	1.15	0.88	36.31	0.79
35	0.92	1.16	0.89	37.04	0.82
40	0.92	1.18	0.91	38.53	0.89
45	0.92	1.19	0.92	39.20	0.92
50	0.92	1.20	0.93	40.04	0.96
55	0.92	1.21	0.94	40.81	1.00
60	0.92	1.21	0.95	41.24	1.02
65	0.92	1.22	0.96	42.02	1.06
70	0.92	1.22	0.97	42.46	1.08
75	0.92	1.23	0.98	43.25	1.12
80	0.92	1.24	0.99	44.05	1.16

(Table:-2.1 Design Wind Pressure)

Height of tower (m)	$F= C_f A P_z (KN/m^2)$
10	0.52
15	0.62
20	0.70
25	0.75
30	0.79
35	0.82
40	0.89
45	0.92
50	0.96
55	1.00
60	1.02
65	1.06
70	1.08
75	1.12
80	1.16

(Table:-2.2 Wind Force Acting At Wind Turbine)

The dynamic reaction of a building to an earthquake's vibration is a crucial structural factor that directly affects the building's resistance and, in turn, the amount of danger. Finding out the features of the structure and the earthquake is required for the study of earthquake loads. Response Spectrum technique analysis was used to identify the characteristics of the windmill. The basic time period and mode forms of the structure can be discovered using the Response Spectrum technique analysis.

Understanding the overall behaviour of windmill constructions built on soil layers was the main goal of this investigation. The analysis of the various windmill towers using the Response Spectrum approach was done by treating the tower as a continuous system. Natural time period can be calculated from the equation by thinking of the tower as a cantilever beam that is locked at one end and free at the other.

S. No.	Item	Critical design results
1.	Footing Diameter (mm)	24000
2.	Footing Thickness (mm)	1000
3.	Reinforcement at bottom face of the footing	25mm∅ at 150mm C/C
4.	Reinforcement at top face of the footing	20mm∅ at 150mm C/C
5.	Lateral ties	12mm∅ at 250mm C/C

(Table:-2.3 Critical Raft Foundation Design Details)

3. Shrestha, S., Ravichandran, N., & Rahbari, P. (2018). Geotechnical design and design optimization of a pile-raft foundation for tall onshore wind turbines in multi layered clay. International Journal of Geomechanics, 18(2), 04017143.

This research presents a liability-based resilient design method for a pile-raft foundation supporting a 130-m wind turbine on layered clayey soil. After the geotechnical design for the mean wind speed and undrained shear strength was finished, a parametric study and Monte Carlo simulation were done to determine the relationship between the design variables (number and length of piles, and radius of the raft) and the random variables (wind speed and undrained cohesion). Finally, a liability-based robust design was developed with robustness and overall cost as the main goals.

The differential settlement's standard deviation, which is a reaction of concern, was used as the robustness metric. The Pareto front, a collection of preferred designs produced by the optimization, was used to identify the best design given a specific cost ceiling and performance criteria.

The third power of wind speed is directly related to wind energy.

From 80 to 100 m of turbine height, the wind speed increases by 4.6%, resulting in a 14% increase in power output, and from 80 to 120 m of turbine height, the wind speed increases by 8.5%, resulting in a 28% increase in power output.

In addition to increasing the lateral load and bending moment at the base of the tower, a taller wind turbine tower also increases the vertical dead load.

This paper presents a geotechnical design and optimization method for a pile-raft foundation for a hypothetical 130 m tall hybrid wind turbine tower with a probable wind farm location in Charleston, South Carolina, with a mean wind speed of 201.17 km/h.

The fundamental concept behind the usage of a pile raft is to increase the foundation's bearing capacity by using a raft and to reduce total and differential settlements by using deep foundations. The most difficult part of designing a pile-raft foundation is quantifying the precise percentages of the overall loads carried by the raft and by the piles.

3. METHODOLOGY

- Finalizing the various height of wind turbine lord calculation from the Foundation (Ex: 100m, 110m, 120m, 130m)

- Adopted method of Design & Types of Foundation(Ex: Spread Foundation, pile Foundation)
- Select the Suitable Software to use design of foundation (Staad. Foundation, Finite Element, SAFE)
- Geotechnical Design
- Structural Design
- Design of Fatigue load & Crack Width Calculation
- Economical Calculation
- Comparison and analysis which types of Foundation is suitable of various types of soil.

4. CONCLUSIONS

According to the various types of soil strata, the normalized base shear and moment owing to shear are all rising. When analyzing a windmill, the drag force, or impact of the wind on the blade, is more important since it causes more significant structural changes. The stability and safety of windmills are significantly influenced by soil layers. When wind impacts are taken into account, a windmill's stability needs to be carefully examined. When analyzing windmills, the effect of wind must be taken into account because it is more significant than the effect of earthquake.

In this study results of the deterministic geotechnical design revealed that rotation and a different settlement were responsible for controlling the final design. The best solution for fulfilling the design requirements was discovered to be the use of the pile raft, which makes use of both the raft and the piles to manage the bearing capacity and settlement, respectively. The parametric study's findings demonstrated that, in order to meet the design specifications at high wind speeds, either the number of piles, the length of the piles, or the radius of the raft can be increased. The Pareto front developed from the design optimization findings revealed a clear trade-off link between the foundation's overall cost and the response's standard deviation (differential settlement). Using the knee point notion, such a relationship is helpful for choosing the preferred design for the specified situation.

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