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A Review on Performance Evaluation of Sustainable Concrete Using Waste Foundry Sand

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***Abstract*— It has become incredibly challenging to get land for power transmission lines year after year due to different limitations, like density of population in the urban areas, obtaining forest clearances and nature protection theory. It is necessary to develop technically compact transmission line tower structures to minimize the tower dimensions. Failure of such structures is a major concern. It is very essential to consider appropriate parameters for designing of these towers in order to enhance their sustainability.**

The present work describes the analysis and design of four-legged self-supporting steel transmission line towers models with an angle sections. The performance of various bracing system has been identified and reported. The lateral wind load resistance is a main measure to evaluate the structural performance of towers. Bracing system is the major system providing lateral load resistance in steel lattice towers. Wind loading is calculated as per IS: 802 (2015).

Using STAAD PRO v8i analysis and design of tower has been carried out as a three-dimensional structure. The analysis has been done by taking different combination of loads. The present work describes the analysis and design of transmission line tower of 30 meter height viz. various parameters. The tower is designed in wind zone – V. The various factors including environmental and materials used for the structure is also considered. The load calculations were performed manually but the analysis and design results were obtained through STAAD Pro. Gust factor method is used for wind load analysis.

Transmission Line Towers comprise around 28 to 42 percent of the total cost of the Transmission Lines. The increasing demand for electrical energy can be met more economical by developing different light weight configurations of transmission line towers. In this project, an attempt has been made to make the transmission line more cost effective keeping in view to provide optimum electric supply for the required area by considering unique transmission line tower structure.

Transmission line towers carry heavy electrical transmission conductors at a sufficient and safe height from ground. In addition to their self-weight they have to withstand forces of nature like strong wind.

Keywords- Transmission tower, lateral wind load, STAAD Pro, Gust factor method, angle sections.

I. INTRODUCTION

Electrical transmission networks are essential for economic development and uninterrupted power supply. Transmission towers support conductors at safe elevations while resisting environmental loads.

Transmission towers are highly susceptible to wind forces because of:

- High slenderness ratio
- Large exposed surface area
- Flexible structural configuration
- Dynamic interaction with conductors

Wind-induced failures account for a significant percentage of transmission tower collapses worldwide.

Proper design requires:

- Accurate wind load estimation
- Efficient bracing arrangements
- Economical steel utilization
- Compliance with design codes

Modern software such as STAAD.Pro enables engineers to perform advanced three-dimensional analysis and optimize tower configurations.

II. NEED OF THE STUDY

Failures of transmission towers primarily occur due to:

- Extreme wind events
- Cyclones
- Inadequate bracing arrangements
- Improper load estimation
- Structural instability

Therefore, optimization of tower geometry and bracing systems is essential to:

- Reduce structural displacement
- Improve stability
- Minimize steel consumption
- Reduce construction cost
- Increase reliability

III. LITERATURE REVIEW

3.1 Ramniwas,(2018),Presented Paper On A Literature Review On Foundry Sand Concrete Concluded That: Solid waste management is the world's most pressing challenge, owing to ever-increasing quantities of waste materials and industrial by-products. Due to a scarcity of land-filing area and its ever-increasing cost, recycling and exploitation of industrial by-products and waste materials are becoming increasingly popular. The use of such components in concrete not only makes it more cost-effective, but it also helps to alleviate disposal worries. Large-scale building is depleting natural sand supplies. As a result, finding a natural sand alternative that may be utilised as a partial replacement for natural sand is critical (fine aggregate). Several forms of waste material by-products have been investigated for use as a partial replacement for fine aggregate in concrete.Coal bottom ash, recovered fine aggregate, sewage sludge ash, stone dust and glass cullet, and waste foundry sand are examples of such products. The current study looked at the effects of using leftover foundry sand as a partial replacement for fine aggregate (sand) on the characteristics of two concrete grades (M20 and M30).

3.2 Neslihandogan-saglamtimure, (2018) Presented Paper On Waste Foundry Sand Usage For Building Material Production : A First Geopolymer Record In Material Reuse Concluded That: Foundry is the process of solidifying molten metal in a mould with space in it to get a particular shape. Foundry is the process of making parts by melting metals or alloys and pouring them into a prepared mould in factories and workshops that make parts for the automobile, construction, and machine industries. Foundry sand is used to mould foundry products in the steel industry. Sand moulds are used in a substantial part of the casting process. 4-5 tones of sand are required for 1 tone of foundry.These proportions may be altered depending on the type of metal to be casted, the size of the item, and the moulding technique used. Foundry sand is described as sand that contains more than 90% silica and 7-15 percent clay (bentonite and kaolinite clay) and has a sintering temperature of over 1500 degrees Celsius. Foundry sands are found in abundance in nature and have a porous structure.

3.3 S.S. Jadhav, S. N. Tande, A.C. Dubai,(2017), Presented Paper On Beneficial Reuse Of Waste Foundry Sand In Concrete Concluded That: Previously discarded industrial byproducts are now being investigated for useful use. Beneficial use can minimise our nation's carbon emissions and virgin material use while also providing economic benefits. It is a key component of a country's stability. Source reduction and waste avoidance come first in the waste management hierarchy, followed by reuse, recycling, energy recovery, and disposal. Today, research is focusing on ways to use industrial or agricultural waste as a source of raw materials for enterprises all over the world.

3.4 Vemma Reddy, S.Shridhar, Etal,(2017), Presented Paper On International research of engineering and technology and Concluded That: The performance of concrete containing waste foundry sand in place of fine aggregate in both fresh and hardened states. They tested foundry sand replenishment on cubes and cylinders with a 20 percent to 100 percent replacement rate. They discovered that when the percentage of foundry sand in the concrete increases, the slump of the concrete reduces. The use of 20% foundry sand instead of regular sand raised the concrete's compressive strength by 13.42 percent. According to their findings, up to 60% of foundry sand contributes to the compressive strength of concrete. The split tensile strength increased up to 60% when foundry sand was replaced, then decreased to 100%.

3.5 A. Naveen Arasu, S. Vivek, J Robinson, T. ThilakRanjith(2017), Presnted On Eperimental Of Wasre Foundry Sand In Partial Replacement Of Fine Aggregate In Concrete Concluded That: An experiment was conducted, and it was discovered that when the WFS ratio increased, the WFS ratio decreased. Natural sand was replaced with 5 percent (0, 5 percent, 10%, 15%, and 20%) WFS by weight. The sum of five concrete mix proportions (M1,M2,M3,M4,M5) were cast with and without WFS to

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determine how to reduce slump and improve workability of fresh concrete. At the ages of 7, 14, 21, and 28, compressive tests were performed to determine the compressive strength of concrete. The results of the tests show that using WFS as a partial replacement for fine aggregate increases the compressive strength of plain concrete. The findings also meet the permitted limitations defined by the American Concrete Institute.With a rise in the WFS substation rate, the concrete's workability diminishes due to the WFS's fitness and high water absorption qualities, as well as the WFS's reclamation. The strength parameters of the concrete mixture comprising WFS and WFS reclamation up to 20% were relatively near to the strength value of cm at all ages of the concrete.

3.6 PendhariAnkush R. DemseDhananjay G., NikamMadhuri E. KarpeBalraj E., KhsirnarPramod R., SuryawanshiPriyankaR.,(2017), Presented Paper On Partial Replacement Of Sand By Waste Foundry Sand Concluded That: In the construction business, fine sand is currently used. This paper also encrypts the quantity of waste foundry sand generated. The article also makes a comment on the construction industry's use of discarded foundry sand. The majority of the study is concerned with the amount of foundry sand that can be used as a cementitious ingredient. The percentage of foundry sand that, according to our findings, provides the greatest strength has also been documented. The qualities of cementious material paper are amazing in terms of compressive strength and flexural strength.

3.7 Scoot Seiter, Dominique M. Pittenger,Etal,(2017), Presented Paper On State Of The Practice Literature Scan For Foundry Sand Concluded That:

Using foundry sand waste products in transportation applications is "technically sound, financially competitive, and environmentally safe," according to the Federal Highway Administration and the US Environmental Protection Agency (FHWA 2004). According to the EPA, utilising foundry sand in construction could save more than 200 billion BTUs of energy and avert 20000 tonnes of CO2 emissions (AFS – FIRST 2016). Foundry sand reuse is also a good way to "preserve virgin sands" and "conserve landfill capacity" (MarylandDOT 2016). As a result, "extensive market development activities by the [EPA] & [FHWA]" (AFS – FIRST 2016) have been focused on increasing the usage of foundry sand.

In 2016, a synthesis effort evaluated current practice and studies related to foundry sand use in transportation construction **(MarylandDOT 2016).**"Potential problems pertaining to material performance, environmental considerations, design, and field performance" were found in the study. Three of the responding DOTs indicated low use of foundry sand in a survey performed by the AASHTO Subcommittee on Materials.

3.8 Deepak Chaurasiya, KiranKoli, SurajChaudhari, Vardan More, P. C. Satpute, (2016), Presented Paper On Utilization Of Foundry Sand : An Art to Replace Fine Sand With Foundry Sand Concluded That: For its moulding and casting processes, the foundry industry uses high-quality specific-size silica sand. This is higher-quality sand than what you'd find in a bank or on the beach. Foundries successfully recycle and reuse sand on a regular basis. It is taken from the industry when it can no longer be reused in the foundry and is referred to as waste foundry sand. There is currently relatively little literature on the usage of these byproducts in concrete. One of the most serious problems in the handling of foundry trash is discarded foundry sand.WFS are colourless and contain a high level of fines. The type of metal poured, the casting process, the technology used, the type of furnace (induction, electric arc, and cupola), and the type of finishing process all influence the physical and chemical attributes of WFS (grinding, blast cleaning and coating).

3.9 Pranitabhandari, Dr. K. M. tajne,(2016), Presented Paper on Use Of Foundry Sand in Conventional Concrete Concluded that: A tiny proportion of bentonite clay is usually used as a binder element in foundry sand. In metal casting, two types of binder systems are utilised, depending on the classification of the foundry sands: 1) a clay-bounded system (green sand) 2) a chemically-bounded system Both types of sands have advantageous properties, but they differ in terms of physical and environmental qualities. The most often utilised reclaimed foundry sand for beneficial reuse is green sand. It is made out of natural materials that have been combined together, including high-quality silica sand (85-95%) and bentonite clay (4-10%) as a binder. Carbonaceous addition (2-10%) to increase the completed casting surface and water resistance (2-5 percent). It has a black colour due to carbon content, a clay content that results in a percent of material passing a 200 sieve, and it adheres together due to water.

3.10 Ravindra N. Patil, Pravin R. Mehetre, Kailash T. Phalak,(2015) ,Presented paper on Development Of Concrete With Partial Replacement Of Fine Aggregate By Waste Foundry Sand Concluded That: Incorporating foundry sand as a metal waste is a recent study topic in concrete. This study was conducted in order to develop an environmentally friendly concrete. This research shows how waste foundry sand can be used as a partial replacement for fine aggregate in concrete. The compressive strength of concrete increases as the percentage of waste foundry sand increases as compared to conventional concrete in both groups. It was set at a maximum of 15% replacement. Split tensile strength increases when the percentage of waste foundry sand is increased up to 15%, after which it declines. The second group of concrete findings, i.e. concrete incorporating artificial sand and WFS, displays more good outcomes, reducing the problem of landfill disposal and maintenance costs. For a 15% replacement of waste foundry sand, the percentage cost change can be as low as 3.5.

3.11 Jaychandra ,Shashi Kumar, A. Sanjith J. DG Narayan,(2015), Presented Paper on Strength Behaviour Of Foundry Sand On Modified High Strength Concrete Concluded That: The main component of foundry sand is high-quality, consistently sized silica or lake sand produced by ferrous and nonferrous metal casting moulds. Before casting, the sand will be pure, but after casting, it will have a ferrous content of around 95% of its own volume. The type and quantity of materials used in moulds are determined by the type of metal that will be cast in the mould. However, in most cases, green sand, which accounts for 90% of the materials, is used in significant quantities. It should be mentioned that the effect of concrete including foundry sand is one-of-a-kind, as the foundry sand alters the physical and chemical properties of the concrete, as well as the production process. It might be used more successfully and efficiently for construction rather than landfilling. The presence of foundry sand affects workability and necessitates the addition of extra water to get a homogeneous mix. The addition of foundry sand to concrete improves the hardened qualities of the concrete by 25%.

3.12 C. G. Konapure, D. J. Ghanate,(2015), Presented Paper On Effect Of Industrial Waste Foundry Sand As Fine Aggregate On Concrete Concluded that:

Massive production waste material from metal companies, which employs foundry sand as a byproduct, now generates a slew of environmental issues. Using these waste products as building materials can assist to reduce environmental stress. Sand is finer than conventional sand and is utilised in the metal casting industry. When burnt sand can no longer be used in metal casting processes, it is taken from the foundry as a waste and disposed of as "waste foundry sand." Waste foundry sand is used as a partial or entire substitution for fine aggregate in concrete, resulting in the creation of cost-effective, light-weight, high-strength concrete. In the research work to explore the various percentages of fine aggregate with used foundry sand, each material in concrete adds its strength or durability of thus, by partial or material that affects the environment can be used for the development of low cost & eco-friendly building material. In order to test the usage of foundry sand as a partial replacement for fine aggregate in concrete, a research study was conducted on a concrete containing foundry sand in the percentages of 0%, 10%, 20%, and 30% by weight for the M20 7 M30 grade of concrete.

3.13 Smit M. Kacha, Abhay V. Nakum, ankur C. Bhogayata,(2014, presented Paper On Use Of Used Foundry Sand In Concrete : A State Of Art Review Concluded That: Industries generate waste, which causes environmental issues. As a result, the importance of reusing this waste material can be underlined. Because of its excellent thermal conductivity, foundry sand has been used as a moulding casting medium for ages. Molding sands are recycled and reused several times during the process. The recycled sand, on the other hand, eventually degrades to the point where it can no longer be used in the casting process. The old sand is displaced from the cycle as a byproduct at this point, and new sand is injected. The cycle starts all over again.It was reported that the researcher's findings with concrete up to 30-40% fine aggregate replacement with foundry sand boosted compressive and tensile strength by 20% while modulus of elasticity did not change significantly. Few researchers go all the way to 100 percent replacement, where strength and durability parameters must be explored more thoroughly in the future.

3.14 Dheeraj N. Kumar, Chidananda M. L.,(2013), Presented paper on Utilization of waste foundry sand in rigid pavement structure concluded that:

The physical and chemical properties of waste foundry sand are heavily influenced by the type of casting process used and the industry sector from which it comes. Sand is typically recycled and reused during numerous manufacturing cycles in contemporary foundries. Industry estimates that roughly 100 million tonnes of sand are utilised in production each year, with 6-10 million tonnes being discarded and available for recycling into other products. For the grade of concrete used in the investigation, the water-cement ratio was 0.42, corresponding to an 80:20 traditional sand ratio. Foundry sand has been shown to have an optimal ratio that provides the highest compressive strength in all ratios.The compressive strength of M1, i.e. the strength acquired for a curing time of 28 days at a 20 percent replacement level, is essentially identical to the standard mix, i.e. normal concrete (NC).

3.15 Dushyant R. Bhimani, JayeshkumarPitroda, Jaydevbhai J. bhavsar, (2013), Presented Paper On study on foundry sand : opportunities for sustainable and economical concrete Concluded that:

There are about 35000 foundries in the world with annual production of 90 million tonnes. The imputes for foundry sector in india was given by the jute industry in Bengol and the cotton industry in Mumbai in late 19^{th}century.India ranks 2^{nd} in the world based on the number of foundry units present 4550 units. They are concluding that 1m3 M20 grade of concrete consumption of fine aggregate is 538.45 Kg. here in specimen M4 we replace fine aggregate by 162 Kg of foundry sand 1m3 M20 grade of concrete. As a result, we can say that up to 30% of foundry sand is used for the economic and long-term growth of concrete. The use of foundry sand in concrete can help save the metal sector money while also producing a "greener" concrete. This research has resulted in the development of an unique supplemental construction material.

3.16 Pathariya Saraswati C., Rana Jaykrushna K,ShahPalas A, Mehta Jay G, Patel Ankit N.,(2013), Presented Paper On Application of Waste foundry sand for evaluation of low-cost concrete Concluded that:

The use of natural resources as concrete materials are both expensive and on the approach of becoming obsolete. These issues urge us to either restore natural resources or discover another way to solve the situation. As a byproduct of the metal casting industry, waste foundry sand is currently causing a slew of environmental issues. In the metal casting process, finer sand is used than ordinary sand. Burnt sand is reused many times throughout the metal casting process, but when it can no longer be used, it is taken from industry as a waste for disposal and is known as Waste Foundry Sand.Concrete is a material made up of coarse aggregate, fine aggregate, cement, admixtures, and water, each of which contributes to the strength of the concrete. As a result, different properties of concrete are affected by partial or percentage replacement of material. Waste materials that are harmful to the environment can be utilised to generate low-cost eco-friendly building materials. Variable percentages of fine aggregate with foundry sand are employed in this study and experimental investigation to generate low-cost and environmentally friendly concrete.

3.17 Khattib and ellies(2008), Presented Paper on effect of waste foundry sand as a partial replacement of sand on the strength, ultrasonic pulse velocity and permeability of concrete and concluded that:

The qualities of concrete containing foundry sand in place of natural sand as a partial replacement. Natural sand has been replaced by three varieties of foundry sand: white fine sand, foundry sand, and WFS (foundry sand without clay or coal). To test these qualities, thirteen concrete mixtures were created. Foundry sand was used to replace 0 percent, 25%, 50%, and 10% of natural fine and class M sand, respectively. They concluded that (a) the concrete made with WFS and white sand had similar strength of all replacement; (b) the strength of concrete was decreased by increasing the replacement percent of foundry sand; (c) concrete incorporating white sand and WFS has more strength than concrete made with blended foundry sand; (d) the length changed of concrete was increased by increasing the replacement percent of foundry sand; and (e) drying shrinkage was increased by increasing the replacement percent of foundry sand.

IV. RESEARCH GAP

Despite significant advancements in the design and analysis of transmission towers, several limitations still exist in the available literature. These limitations create opportunities for further investigation and optimization.

4.1 Limited Studies on Dynamic Wind Pressure for Medium-Height Towers

Most previous studies have concentrated either on very tall Extra High Voltage (EHV) transmission towers or small telecommunication towers. Comparatively fewer investigations have been carried out on medium-height transmission towers (25–40 m), which are widely used in practical power transmission networks.

Medium-height towers exhibit unique structural behaviour because their stiffness, flexibility, and dynamic response characteristics differ from both low-rise and very tall towers. The influence of dynamic wind pressure on these structures is not yet fully understood, especially under varying terrain conditions and wind zones.

Therefore, there is a need for comprehensive research specifically focused on medium-height transmission towers subjected to dynamic wind loading.

4.2 Insufficient Comparison Between K-Bracing and X-Bracing Under Broken Wire Conditions

Bracing systems significantly influence the overall performance and stability of transmission towers. Although several researchers have studied different bracing arrangements, only a limited number of studies have directly compared K-bracing and X-bracing systems under broken wire conditions.

Broken wire conditions generate unbalanced forces that produce additional longitudinal and torsional effects on the tower. These conditions may lead to excessive displacement, increased member forces, and even progressive structural failure if not adequately considered.

A detailed comparative study is therefore necessary to evaluate the performance of K-bracing and X-bracing under both normal and broken wire conditions.

4.3 Limited Utilization of Updated IS 802:2015 Provisions

Many existing studies have been performed using earlier versions of IS 802 or simplified design approaches.

However, IS 802:2015 introduced several important updates, including:

- Improved wind loading methodology
- Gust response factors
- Revised reliability requirements
- Enhanced safety provisions
- Detailed loading combinations

The application of these updated provisions in practical transmission tower analysis is still limited. More studies are required to validate and implement the latest code recommendations.

4.4 Limited Optimization Considering Both Structural Performance and Economy

Most previous studies focus either on structural safety or material economy independently.

Few researchers have simultaneously considered multiple performance parameters such as:

- Maximum displacement
- Internal member forces
- Structural stiffness
- Steel consumption
- Overall cost effectiveness

A balanced optimization approach is required to develop efficient and economical tower designs without compromising structural safety.

4.5 Limited Comparative Studies Between Normal and Broken Wire Conditions

Transmission towers experience different loading scenarios throughout their service life. While many studies focus only on normal operating conditions, broken wire scenarios are often neglected.

Broken wire conditions represent accidental loading situations that may generate:

- Additional torsional effects
- Large longitudinal forces
- Significant displacement
- Increased risk of collapse

A comprehensive comparison between normal and broken wire conditions is essential to evaluate the overall reliability and robustness of the transmission tower.

V. EXPECTED OUTCOME

The outcomes anticipated from this study are discussed below.

5.1 Improvement in Structural Stability

The optimized bracing configuration is expected to enhance the stiffness and overall stability of the transmission tower under dynamic wind loading.

5.2 Reduction in Excessive Displacement

Proper bracing arrangement is expected to significantly reduce lateral displacement and improve serviceability performance.

5.3 Minimization of Steel Quantity

Efficient load transfer mechanisms can reduce unnecessary steel usage and improve structural economy.

5.4 Enhancement of Wind Resistance

The tower will be able to better resist dynamic wind actions, thereby improving reliability and reducing the risk of failure.

5.5 Optimization of Overall Tower Performance

The study will help identify a balanced design that simultaneously satisfies:

- Safety requirements
- Serviceability requirements
- Economic considerations
- Code compliance requirements

VI. CONCLUSION

Transmission towers are highly vulnerable to wind-induced forces due to their slender and open lattice configuration. Dynamic wind pressure considerably affects structural responses such as displacement, axial forces, bending moments, and overall stability.

The selection of an appropriate bracing system plays a crucial role in determining the efficiency and economy of transmission towers. Previous studies have demonstrated that both K-bracing and X-bracing systems provide satisfactory performance under wind loading conditions.

However, each bracing configuration exhibits different behaviour with respect to stiffness, displacement, force distribution, and material consumption.

Moreover, accidental loading conditions such as broken wire scenarios can generate additional stresses and significantly alter the structural response of the tower. Therefore, it is essential to evaluate tower performance under both normal and abnormal operating conditions.

The use of updated IS 802:2015 provisions, combined with advanced analysis software such as STAAD Pro, allows engineers to obtain more realistic and accurate results.

Future research should focus on:

- Nonlinear structural analysis
- Wind-structure interaction
- Aerodynamic effects
- Fatigue assessment
- Performance-based design approaches
- Artificial intelligence-based optimization techniques

Such advancements will contribute to safer, more reliable, and more economical transmission tower designs capable of meeting future energy infrastructure demands.

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