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Design of Earthquake Resistant Structure Using Cabkoma Strands: A Review

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Abstract: Earthquakes are the indication for transformation of earth internal surface. The Indian subcontinent has suffered some of the greatest earthquakes in the world. Many research studies have been focusing on decreasing the impact of seismic waves on structures. For this initially there were many passive techniques introduced to reduce the damage caused due to earthquakes which are based on decreasing the lateral loads on structures. But since the late twentieth century the focus has shifted to introduce active earthquake techniques which are meant to absorb the seismic waves or do not let the waves propagate through the building. Though it is not possible to prevent an earthquake, the least that can be achieved in reducing the damage is to make the buildings earthquake resistant with the advancements in earthquake resistant techniques.

The major goal of this dissertation is to use CABKOMA strands to create a novel earthquake-resistant technology. In this study, CABKOMA strands are used to examine the seismic response of ordinary moment resisting steel framed structures of high rise, mid-rise, and low rise analyzed with and without strands to determine the workability of cabkoma strands. To determine how well the intended structures function against earthquake motions, a comparative examination is done between them. Additionally, this work shows a comparative analysis of the seismic behavior of high-rise, mid-rise, and low-rise steel structures designed utilizing CABKOMA strands with the seismic behavior of high-rise steel structures designed using bracings an existing earthquake technique, by varying the arrangement of strands at the corner, Centre, and both centre and edge of the structures. Eventually, this work presents cabkoma strand optimization for effective strand utilization by varying strand to strand spacing from 0.5m to 1m while maintaining the same strand positioning.

Index Terms: CABKOMA Strands, High – rise steel structure, STAAD pro, Bracings

I. INTRODUCTION

Earthquakes are known to have tremendous potential in causing a devastating impact on the built environment and human life. India has witnessed over 9 severe earthquakes in the last two decades between 1990 and 2010 and reports claim the death rate to be around 30000 [3]. Although certain parts of the country are more prone to earthquakes (seismic zone V of IS 1893(Part 1)- 2016) than the rest, no region can be considered as free from earthquakes. In the Indian scenario, multiple micro earthquakes are reported near the subduction zone (Himalayan belt) on a daily basis, whereas in the intraplate region (Deccan plateau) few major earthquakes have been witnessed over the years.

The performance of the built environment during the past earthquakes has demonstrated its fragile nature and has created an urge among the engineers and architects to move towards seismically efficient buildings.

The majority of the Indian landmass (about 60%), is susceptible to moderate to very severe earthquakes. A great earthquake in an uninhabited area may produce minimal damage when compared to a moderate earthquake in a densely populated area. All the field survey studies conducted after a major earthquake implied that the maximum casualties reported were caused by building collapse. The lack of earthquake knowledge and its incorporation in the building design and execution leads to failure of buildings. A large part of the rural and urban dwellings are low rise non engineered buildings and these suffer maximum damage.

During an earthquake, the seismic waves propagate in all directions. However, among the various components, the horizontal vibration is considered to be most predominant in causing structural failure. The seismic waves tend to move the foundation of a building inducing inertial forces in various structural elements. The seismic performance of a structure during an earthquake depends on its overall shape, size, geometry and the nature of load path. The seismic design philosophy aims to ensure safety to structural components and human life.

It states that the load-bearing structural elements must suffer no damage in the event of a (frequent) minor shaking, sustain reparable damage in the event of (occasional) moderate shaking and sustain severe damage without collapse under (rare) strong shaking.

Necessity for the earthquake resistant construction:

Earthquake resistant design consists of an evaluation of the earthquake excitation and the structure response to this excitation at a particular site in order to provide a structural system that will not collapse, that may prevent loss of life and will limit economic loss during an earthquake. Earthquake-resistant construction, the fabrication of a building or structure that is able to withstand the sudden ground shaking that is characteristic of earthquakes, thereby minimizing structural damage and human deaths and injuries.
As per the geological survey of India (GSI), more than half of the Indian landmass is vulnerable to earthquakes. Estimates also suggest that by 2050, more than 200 million city dwellers in the country would be exposed to storms and earthquakes [4]. So, it extremely essential for homebuyers in India to ensure that their housing units stand tall in the case of an earth-shaking catastrophe. Not only is it important for the safety of life, but also from the standpoint of long-term security of investment.

A. CABKOMA Strands As Earthquake Resistant Material

The CABKOMA strand rod is made of a carbon fiber composite. Thin, oriented carbon fiber strands are used for the interlining. They are covered by an outer layer composed of synthetic and inorganic fibers intended to protect against weathering of the carbon fibers. The combination is then impregnated with thermoplastic resin. It was developed by the Komatsu Seiten Fabric Laboratory in Ishikawa, Japan[7].

Section of CABKOMA Strand Rod

CABKOMA strand rod is the lightest seismic reinforcement system in the world (KOMATSU MATERE Co., Ltd., 2019). It has a high tensile strength, a "delicate but strong structural body," and a superb aesthetic quality. The material has a specific weight of about one-fifth of that of typical steel rebar. In fact, a 160-meter (525 feet) roll of the strand rod weighs only 12 kg (26.5 lbs) Yet it still has greater tensile strength per unit area [6].

Comparison of CABKOMA strand rod and Rebar

Properties	CABKOMA strand rod	Rebar
Diameter	5.83mm	6mm
Cross sectional Area	26.7mm^2	28.3mm^2
Tensile strength	38.22kN	5.67kN
Tensile strength per Unit Area	1.43 kN/mm^2	0.2kN/mm^2

Size Comparison of Strand Rods Vs Rebar

Many sectors utilize the carbon fiber and thermoplastic composite material. The benefits of the material being lighter in weight while still maintaining strength as compared to other materials make it valuable across many industries. For example, the composite has many applications in the nautical and transport trades. Its workability due to the thermoplastic impregnation and the ability to recycle the material are highly advantageous attributes. This composite has been used to make lighter automobiles and aircrafts, reducing their fuel consumption and making their overall design more efficient (Arkema, n.d.). The above figure illustrates the difference in diameter between the two materials while they are still equivalent in terms of strength.
The strand rod also has the potential to add an element of aesthetic appeal to a structure. Typically, seismic reinforcement systems are designed to be disguised within building finishes. The Komatsu Seiten's headquarters is a unique example of how a seismic retrofit reinforcement system can double as an architectural element.

II. CRITICAL REVIEW ON DESIGN OF EARTHQUAKE RESISTANT STRUCTURE USING CABKOMA STRANDS

Umezawa Akira (2020) investigated on a new rust-free material that is stronger and lighter than steel.Author stated that A textile company in Ishikawa Prefecture has developed a carbon fiber composite material, a new material stronger than steel, by applying a traditional Japanese braiding technique known as kumihimo. This CABKOMA is currently gaining attention especially as a material for seismic resistance in earthquake-prone Japan. To make CABKOMA, seven strands of carbon fiber are each wrapped in a sheath of multiple glass fibers in the braided manner of kumihimo then twisted together and soaked in resin to form a wire. Its biggest features are that it is lightweight, strong and rust-free. With a weight one-fifth the weight of steel and approximately ten times the strength, it also has superior heat and chemical resistance.
Ordinary carbon fiber has strong elasticity, but is weak to parallel force. CABKOMA, however, is strong and flexible due to the glass fibers covering the carbon fiber core being braided like kumihimo. It has a diameter of 9 mm, but even an approximately 160-meter-long strand weighs only 12 kg, and can be carried by hand. It is just one-fifth the weight of conventional metal wire but with the same level of strength. In 2015, Komatsu Matere used CABKOMA as a material for seismic resistance for renovations of their headquarters at the time. CABKOMA was not only attached like bracing on the interior of the building, but it also connected the roof of the building with the ground on the exterior. "CABKOMA was certified as a Japanese Industrial Standards (JIS) standard for a material for seismic resistance in 2019 – the first such certification for a carbon fiber composite material."
Author concluded that CABKOMA can be used in the same way as steel is used in steel-reinforced concrete. The deterioration of steel-reinforced concrete begins with the steel inside the concrete rusting. If CABKOMA is used in place of steel, it will be possible to expand the current 50-year lifespan of steel-reinforced concrete to over 100 years.
Larissa D. P. Eshelman (2019) investigated on CABKOMA Strand rods and high-performance fiber-reinforced cementitious composites as earthquake resisting materials. These methods have a promising future due to their ease of use, cost efficiency, and minimal interruption to the continued use of the structure. The addition of strand rods on the interior or exterior of a structure provide a lightweight seismic reinforcement retrofit solution. Using these rods to create infill shear walls or exterior tie-downs provide resistance to lateral forces incurred by structures during a seismic event. The thermoplastic nature of the composite material increases its workability, allowing for faster installation. The carbon fibers used within the strand rods provides greater strength with less weight.
When applied to the exterior, strand rods slightly increase the footprint of a building. Therefore, adequate room surrounding the building must be present. Strand rods provide design flexibility as they can be used on existing structures of varying composition, age, heights, and configurations.Author concluded that Both methods discussed in this report are new and still under development.

Further research is needed to advance the materials and methods of application. Additional studies can provide deeper insight into the behavior of these materials and to find more efficient ways to apply them. More experimental and analytical data are necessary to codify the methods and to develop design guides that can be utilized by practicing engineers.

The materials and methods discussed in this report have the ability to be applied to structures of various shapes and compositions including historically landmarked properties. The versatility, constructability, and optimized installation timeline make these methods viable options that warrant consideration as retrofit solutions for structures located in seismically risky regions.

E P Dorofeev[1], N N Dorofeeva[2] (2021) investigated on using composite materials as earthquake resistant material which have become a mandatory part of this area. Designing large-scale projects can no longer do without composite. Stable, simple, and also reliable, it has significant advantages in comparison with real materials, which are difficult to change their configuration. A variety of building components, such as arches or domes, are often formed using composite materials. We believe that this is profitable from the point of view of the industry, as it makes it possible to significantly save our money in the construction of structures, installation, storage and transportation of the composite. Based on these data, they have analyzed various types of composite materials, and also revealed their characteristic features. It was concluded that composite materials are one of the most demanded material resources of modern industrial production. Especially, they are widely and efficiently used in high-tech industries. Products made of composite materials are highly competitive in quality and relatively low price. One of the main advantages of composites is a unique combination of deformation, thermal conductivity, strength, impact resistance, temperature, elasticity, electricity, friction, and other properties that are not inherent in traditional materials. The trends in this direction have much in common in various sectors of world industry, and thus have a positive effect on the development of the modern world.

Katta Venkataramana [1] , Shreyasvi C [2] (2018) Studied about recent advances in earthquake resistant construction practices.Author investigated the construction practices adopted for these common building typologies. Recommendations are made for the local construction practices wherever found necessary with relevance to the codal provisions. In addition, the possible future trend in the earthquake resistant technology has also been discussed which also involves Cabkoma strands in it.Author concluded that earthquake safe construction technology should mainly involve usage of materials of ductile nature, earthquake resilient building configuration, lightweight structural components to reduce the seismic forces and robust architectural forms.

Shunsuke Otani (2017) studied about Japanese development of earthquake resistant building design. In his study author considered various earthquakes and various upgrades in building design with time and came to the conclusion that the technical development of earthquake resistant building construction reduces the significant vulnerability of new construction. The structural damage can be significantly reduce by regulating following: The eccentricity between the centers of mass and stiffness in plan, The irregular configuration of structures in plan, and controlling the quality of construction work, The discontinuity in stiffness and strength along the height of buildings, The brittle modes of member failures such as shear failure of reinforced concrete columns.

Prof. (Dr.) Omprakash Netula studied about various earthquake resistant techniques. Author has done the analysis of earthquake resistance building. Author studied about the Various techniques exists to provide resistance to the building against earthquake for which proper analysis of the site/ building has to be done. Author concluded that earthquake resistant structures are important nowadays, to withstand the seismic effects. It cannot be avoided but by following various methods and techniques we can reduce the damages and risks to the structures and lives.

Fasil Mohi ud Din [1] Pavitra.C [2] Dr. M.Muthukumar [3] Studied on time history analysis of base isolated steel structure.Their main part of study was to check the response of the base isolation of the steel structure under time history analysis. Base isolation is one of the most widely accepted seismic protection systems used in structures in earthquake prone areas. The base isolation system separates the structure from its foundation and primarily moves it relative to that of the upper structure. The aim of this study is to reduce the base shear and story drifts due to earthquake ground excitation, applied to the superstructure of the building by installing base isolation devices at the foundation level and then to compare the different performances between the fixed base condition and base-isolated condition. In this study, the (G+9) unsymmetrical steel. Structure is used as test model. Friction base isolator is used as isolation system in this study. Nonlinear time history analysis is used on both of fixed base and base isolated structure. The comparative study of the acceleration, displacement and base shear was carried out for both fixed base and base isolated structure. It is found that the displacement is increased with period of the structure in case of base isolated structure and the acceleration is reduced and vice versa.

Anusha[1] , U.Arun Kumar[2] aimed to analyze and design of a multi-bay and multi storied(G+5) steel structure for earthquake forces following IS 1893-2002 and design as per IS 800-2007.The selection of arbitrary sections have been done following a standard procedure and corrections are done accordingly for earthquake loads. The two methods that have been used for analysis are Equivalent static load method and Response Spectrum method.

The frame has also been further checked for P-Δ analysis and required corrections has been done and final results are documented. Finally, the design of connection of an interior joint and an exterior joint of the frame have been done and the calculations have been shown and figures are drawn. The cost efficiency of both the methods have been compared.

Behzad Mohammadzadeh[1] and Junsuk Kang[2] (2020) investigated the seismic responses of high-rise steel-frame building of twelve stories with various stiffness irregularities. The building has five spans of 3200 mm distance in both X- and Y-directions. SAP2000 was used for the design purpose. It resulted in the various sections for different stories; one to three: 0.50×0.50×0.05m, four to seven: 0.45×0.45×0.05m, and eight to twelve: 0.40×0.40×0.05m. The FEM software ABAQUS was used for the time-history analysis of the buildings subject to real data recorded from Vrancea Earthquake in Romania was adopted to perform nonlinear incremental dynamic analysis. First, the regular building was modeled and analyzed, then, the irregular buildings were modeled. The results were extracted for two peaks of seismic acceleration at both negative and positive phases. For the regular building, deformed shapes and corresponding displacements were provided for X-direction due to the symmetric plan of the building laid down in X-Z plane, while the results of irregular buildings were reported in both X- and Z- directions. Thereafter, the support reactions including displacements and moments were reported to provide a good insight into the effects of the irregularity on building seismic. The seismic behavior of the buildings of different types and effects of irregularities were investigated in terms of Storey drift.

III. CONCLUSION

This review paper briefs the efficiency of utilizing CABKOMA strands as earthquake resistant material. The earthquake safe construction technology should mainly involve usage of materials of ductile nature, earthquake resilient building configuration, lightweight structural components to reduce the seismic forces and robust architectural forms. Using CABKOMA strands to create infill shear walls or exterior tie-downs provide resistance to lateral forces incurred by structures during a seismic event. The thermoplastic nature of the composite material increases its workability, allowing for faster installation. The carbon fibers used within the strand rods provides greater strength with less weight. CABKOMA strands are strong and flexible due to the glass fibers covering the carbon fiber core being braided like kumihimo. It is just one-fifth the weight of conventional metal wire but with the same level of strength.Based on the review of various studies findings are concluded as if CABKOMA strands are used as an earthquake resistant material it will be possible to expand the current fifty-year lifespan of steel-reinforced concrete to over hundred years.

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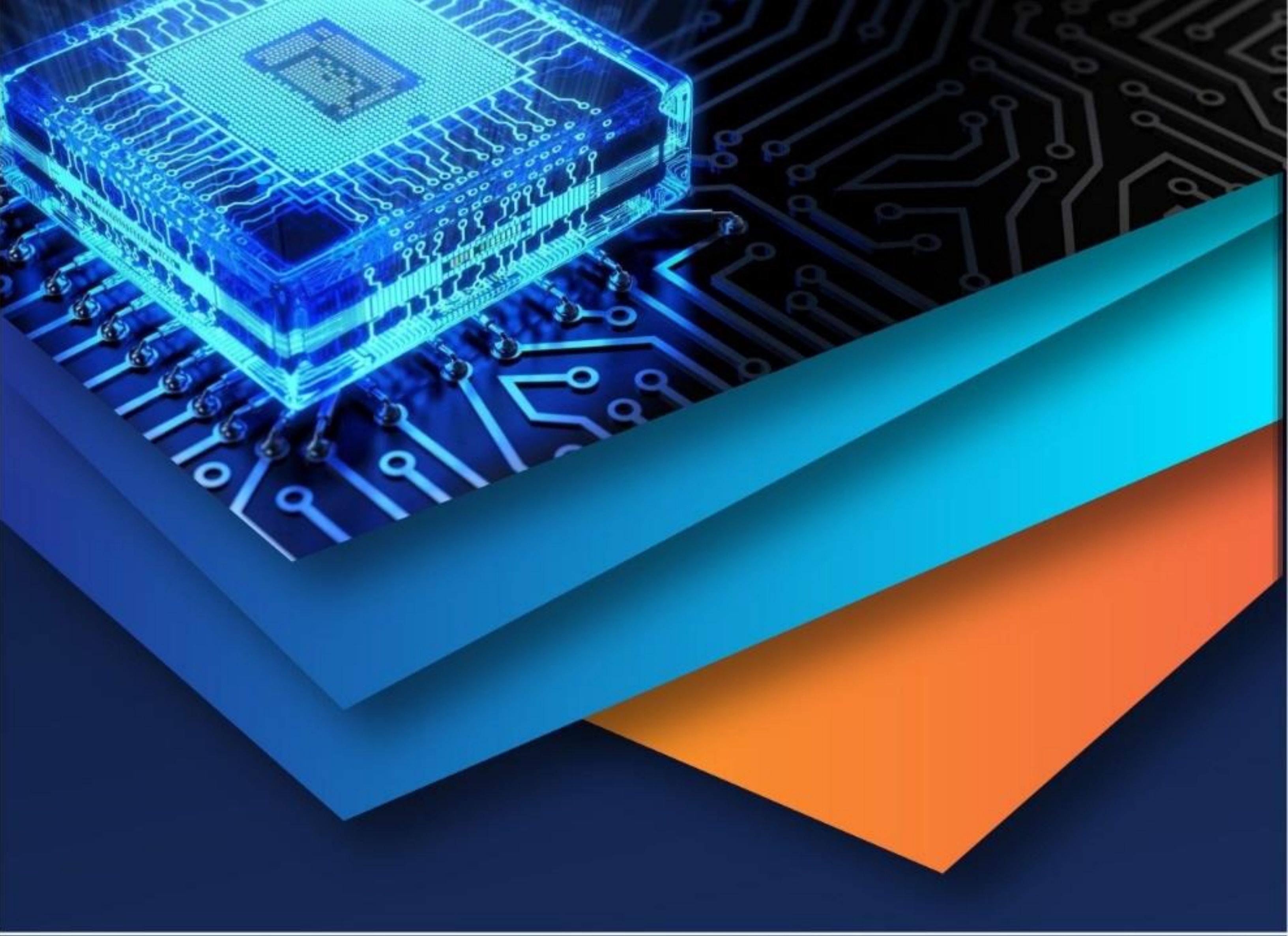

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