

SOIL STRUCTURE INTERACTION IN NON-PARALLEL SYSTEM OF REINFORCED CONCRETE FRAME STRUCTURE WITH CFST COLUMN

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Abstract - Soil Structure Interaction is interaction between the structure and soil that when the structure placed at the ground due to which is developed force on the soils, and soil push the structure. The plan of the structure except the rectangular or square shape is come under the non parallel system such as plan of the structure is just like parallelogram. As we know that now a days construction is going in the vertical means high rise structure due to which the load on the structure is heavy so, to bear that load we are using the Concrete Steel Filled Tube (CFST) Column. We have studied previous research based on the SSI, CFST, Non parallel system, and we found that all author studied the individual parameter, and here compiled all parameter to studied in the single different models. The main objective of this research work to check the stability of the structure among the first model examines a non-parallel RC frame system without SSI and with RC columns, while the second model incorporates SSI effects into a similar RC column structure. The third model explores a non-parallel system without SSI but with concrete-filled steel tube (CFST) columns, and the fourth model evaluates a system integrating both SSI effects and CFST columns. The method used in this research work is Dynamic Analysis by using Time History Analysis.

Key Words: Soil-Structure Interaction, Non-Parallel System, CFST Columns, software.

1. INTRODUCTION

1.1 Background

Soil-Structure Interaction (SSI) is a critical aspect of structural design because it helps engineers understand how the soil and structure influence each other. When a building or bridge is placed on the ground, both the soil and the structure react to the forces between them [1]. Ignoring this interaction can lead to inaccurate predictions of performance, especially during earthquakes or heavy loading. By accounting for SSI, structures can be designed to be safer, more stable, and cost-efficient [2].

Non-parallel structural systems are becoming increasingly popular in modern construction [10-11]. Unlike traditional designs with components at right angles, these systems involve beams and columns arranged at unconventional

angles [3-4]. They allow for innovative architectural designs and complex geometries, making them ideal for futuristic buildings, bridges, and large-scale projects [12]. Non-parallel systems add flexibility, both in aesthetics and functionality, to modern construction practices [5].

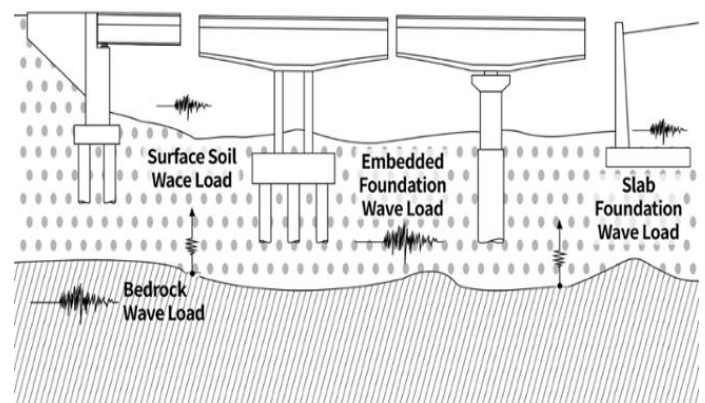


Figure-1: Soil Structure Interaction [17].

1.1.1. Concrete-Filled Steel Tube (CFST) Columns

Concrete-Filled Steel Tube (CFST) columns combine the strengths of two materials: steel and concrete [6]. The steel tube provides external support and confinement, while the concrete inside enhances compressive strength [7]. CFST columns are valued for their ability to handle heavy loads, their durability, and cost-effectiveness. They are widely used in high-rise buildings and bridges, where strength, efficiency, and space-saving solutions are crucial [8-9].

1.1.2. Challenges in Modeling SSI for Non-Parallel Systems

Modeling SSI for non-parallel systems is quite challenging because of their unique geometry and load behavior. Unlike straightforward structures, non-parallel systems have complex load paths and irregular connections. Accurately simulating how the soil interacts with such designs requires advanced software, detailed soil properties, and a deeper understanding of dynamic forces. These challenges make SSI modeling for non-parallel systems a highly specialized and intricate process.

1.2. Non Parallel System

Imagine a building where the main support structures aren't perfectly straight. This can cause the building to twist and turn during an earthquake, making it more difficult and crucial for engineers to design it [21].

If you try to push a square box from the side, it will move smoothly. But if the box is slightly tilted, it'll wobble and might even spin. Earthquakes can have a similar effect on buildings, especially if they aren't perfectly aligned.

Engineers need to use special techniques to ensure these buildings can withstand the shaking and protect the people inside [22]. This involves careful calculations and advanced computer models to predict how the building will behave during an earthquake.

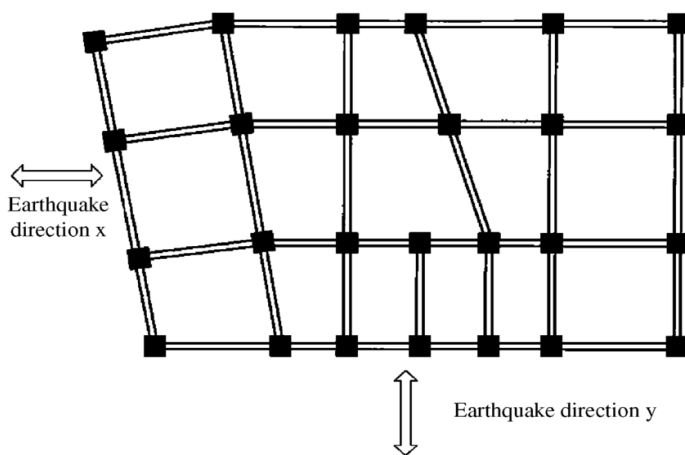


Figure-2: Non Parallel System [16]

1.3. Problem Statement

In the literature review, we found that most of the scholar have studied at the Soil structure interaction in the Reinforced concrete frame structure by using the different types of the foundation, and they are using mainly normal plan of the Structure such as rectangular or square plan.

Scholar did not worked on the combination of Non Parallel structure with Concrete Filled Steel Tube column as well as Normal Reinforced Concrete column in the single type foundation.

1.4. Objectives of the Study

The objective of this research work on Soil Structure Interaction (SSI) in Non-Parallel Systems of Reinforced Concrete (RC) Frame Structures with CFST Columns is to analyze the behavior and stability of four different models using structural analysis software. The first model represents a non-parallel system without SSI using RC columns, while the second model incorporates SSI with RC columns. The third model considers a non-parallel system

without SSI using CFST columns, and the fourth model includes both SSI and CFST columns. To evaluate the stability and performance of these models, several parameters have been selected for analysis. These include determining the lateral forces in all models under load cases EX and EY, assessing the natural time period to ensure it does not exceed 2.00 seconds, and evaluating the lateral displacement under load cases EX and EY. The stress distribution of all models are also determine in this research.

2. METHODOLOGY

2.1 Research Approach

This study adopts a numerical modeling and simulation-based approach to analyze the behavior of a non-parallel reinforced concrete (RC) frame structure with CFST columns under Soil Structure Interaction (SSI). Structural analysis software is used to create and simulate four distinct models with varying conditions, such as with and without SSI, and using RC or CFST columns. Numerical simulations allow for precise evaluation of parameters like lateral forces, displacements, storey drift, and foundation settlement. This approach provides a detailed understanding of structural performance under different scenarios, offering insights into the stability, strength, and dynamic behavior of complex non-parallel systems.

2.2 System Description

2.2.1. Material Used

In this research work, we have used different grade of the materials of the concrete as well as steel, the details of grade of the material is given below in the table:

Table-1: Materials

Serial Number	Grade of the Materials	Used in the modes.
1.00	Grade of Concrete for Column.	M35.
2.00	Grade of Concrete for Beam and Slab.	M30.
3.00	Grade of Concrete for Mat Foundation.	M35.
4.00	Grade of the Steel for Main Reinforcement.	Fe500.
5.00	Grade of the Steel for Transverse Reinforcement.	Fe415.

2.2.2. Geometry of the Building

In this research work, we have used Beam, Column, Slab, plan area of the structure, height of the structure. These types of the details are given below in the form of the table:

Table-2: Building Geometry.

Serial Number	Building Geometry	Dimensions.
1.00	RC Beam	525mm*325mm
2.00	RC Column	625mm*400mm.
3.00	CFST Column	Figure-3.1
4.00	Number of Storey.	G+10
5.00	Height of Ground Floor.	3.25m.
6.00	Height of Each Floors.	3.00m.
7.00	Total Hieght of Struture	33.25m
8.00	Length of the Beam.	4.00 meter
9.00	Thickness of slab.	130.mm

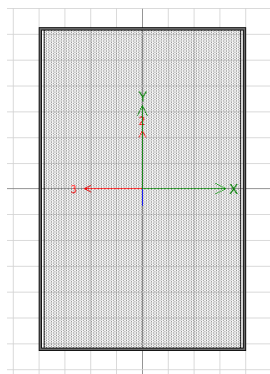


Figure-3: CFST Column.

Here we have selected the thickness of the steel tube is 5mm, and thickness of the steel tube can be increase or decrease depending upon the height of the structure as well as loading case on the structure.

The details view of all models are given below:

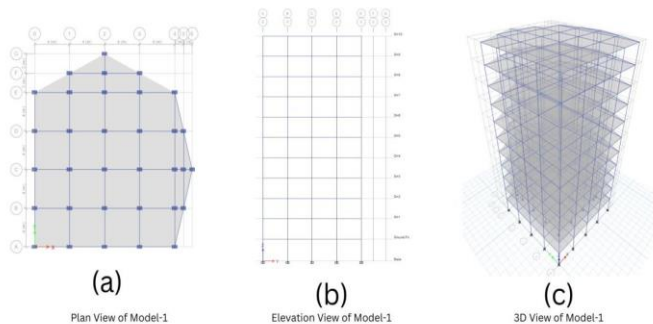


Figure-4: Details View of Model-1.

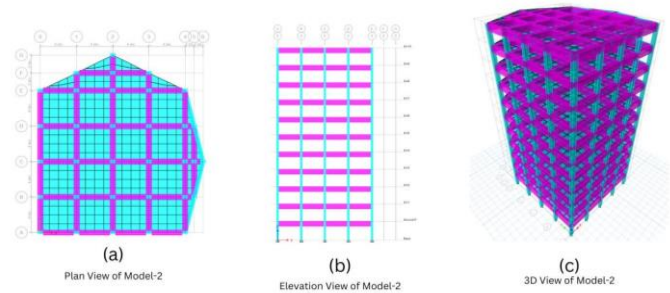


Figure-5: Details View of Model-2.

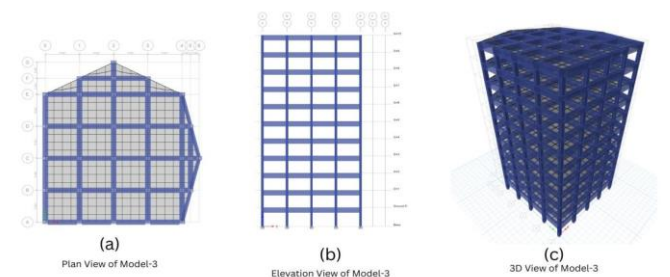


Figure-6: Details View of Model-3.

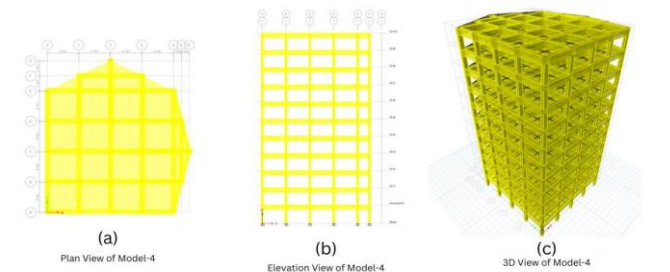


Figure-7: Details View of Model-4.

2.2.3. Seismic Parameter

In this research work, we have used seismic parameter in the non parallel RC frame structures from the Indian standard code 1893 part1:2016 and details of the seismic parameter are given below:

Table-3: Seismic Parameter.

Serial Number	Seismic Parameter	Value
1.00	Seismic Zone (Z).	Z= 0.16
2.00	Importance Factor (I).	1.50
3.00	Response Reduction factor (R).	5.00
4.00	Type of Soil.	Soft Soil
5.00	Time History Analysis	

2.2.4. Load on the Models

In this research work, we have used different types of the load on the models such as the Self weight of the structure, Imposed load on the structure, and seismic load on the structure.

Table-4: Load on the Structure.

Serial Number	Load on the Structure	Value
1.00	Self weight of the structure.	Automatically calculated by the Software.
2.00	Imposed load on the Slab.	3KN/m ²
3.00	Lateral Load on the Structure due to Seismic in the X-Direction of the Structure.	According to IS 1893 part1:2016
4.00	Lateral Load on the Structure due to Seismic in the Y-Direction of the Structure.	According to IS 1893 part1:2016

3.RESULTS AND DISCUSSION

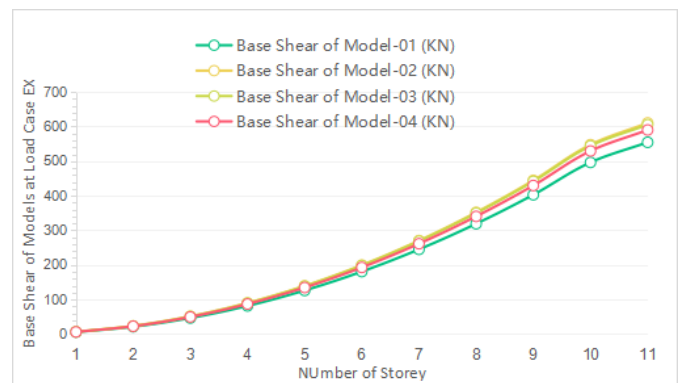
In this chapter of the analysis of result, we will analyze the result which come after analysis of the four models by using the civil software. We will analyse the result on the basis of the some important seismic parameter such as:

- Base Shear (Lateral Force on the Structure).
- Natural time Period of all models.
- Storey Displacement of the Structure at Different Load Combinations.
- Stress Distribution.

3.1. Base Shear of the Models

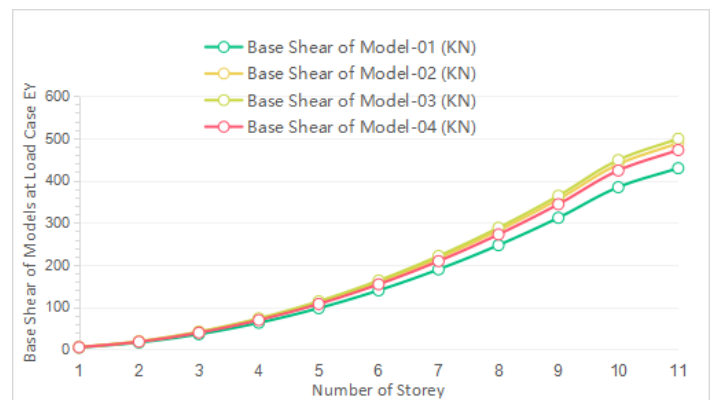
Base shear, as defined by IS 1893 Part 1: 2016, is the total horizontal force that a structure needs to resist at its base during an earthquake. This calculation is essential for designing buildings that can safely withstand seismic forces. The formula involves several factors: the seismic zone factor (Z), importance factor (I), response reduction factor (R), spectral acceleration (Sa/g), and the structure's weight (W). Each of these components helps tailor the base shear calculation to the building's location, importance, and structural characteristics, ensuring that the design appropriately accounts for potential earthquake impact. By following these guidelines, engineers can build safer, more resilient structures in earthquake-prone areas, making base shear a cornerstone of earthquake-resistant design in India.

The value of the base of the all four models at the load case EX is given below in the form of the table as well as graph:



Graph-1: Base Shear of Models at Load Case EX.

The value of the base shear at the load case EY of all models are given below in the table form as well as graph:



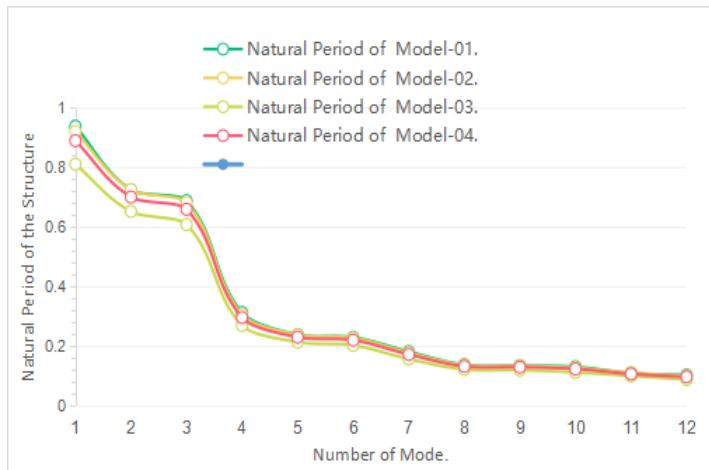
Graph-2: Base Shear of Models at Load Case EY.

3.2. Natural Period of all Models.

The natural period of a structure is the time it takes to complete one cycle of vibration when subjected to dynamic forces, like an earthquake or wind. It depends on the building's height, mass, stiffness, and overall design. Tall and flexible structures usually have longer natural periods, while shorter, stiffer buildings have shorter ones. Knowing the natural period is crucial for earthquake-resistant design because it helps engineers predict how the building will resonate with ground motions. When the natural period aligns closely with the frequency of seismic waves, resonance can occur, amplifying vibrations and potentially leading to greater damage. Therefore, calculating the natural period accurately enables engineers to fine-tune designs to avoid harmful resonances, enhancing the safety and resilience of the structure.

As per Indian Standard Code 1893 part1:2016, the natural period of the structure should be exist between the 0.05 second to 2.00 second up-to G+20 RC Structure, and the

value of the natural period of the structure with and without soil structure interaction are given below in the form of the table as well as graph:



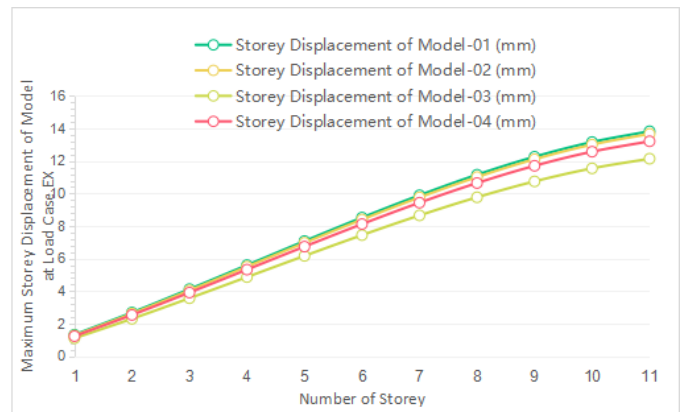
Graph-3: Natural Period of the Models.

3.3.Storey Displacement of the Structure at Different Load Combinations.

Storey displacement refers to the horizontal movement or shift experienced by each floor level of a building when subjected to lateral forces, such as those from wind or earthquakes. This displacement is a natural response of the structure to dynamic loads and depends on factors like building height, stiffness, mass distribution, and the intensity of the applied forces. Engineers pay close attention to storey displacement because excessive movement between floors can lead to structural damage, discomfort for occupants, and, in severe cases, failure of the building. Standards, such as those outlined in IS codes, set limits on allowable storey displacement to ensure stability and safety. By managing this displacement through careful design and structural enhancements, engineers create buildings better equipped to withstand lateral forces, reducing the risk of structural and non-structural damage.

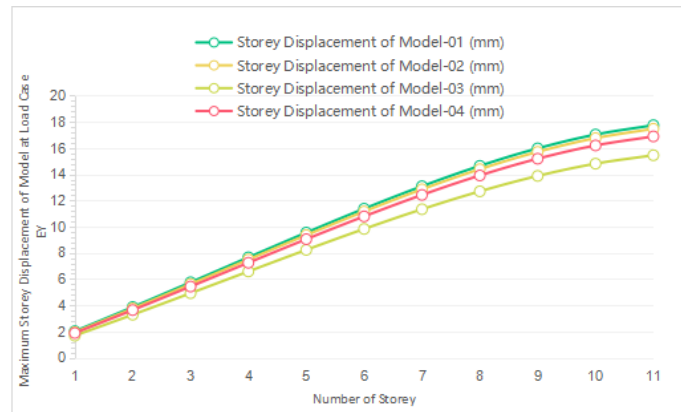
After the analysis of the four models in the soil structure interaction, we have found the result of the storey displacement at the load case EX as well as EY, which are given below in the form of the table as well graph:

The maximum storey displacement of the model at the loads case EX are given in the form of the table as well as graph:



Graph-4: Maximum storey displacement of the model at the SSI at load case EX.

As we have discuss above that we have selected two load case for the analysis of these models that is EY.



Graph-5: Maximum storey displacement of the model at the SSI at load case EY.

3.4.Stress Distribution

When you put weight on it (like people, furniture, or even the wind), forces are created inside it. These forces, called stress, aren't always evenly spread. They can push or pull on different parts of the building in different ways.

Sometimes, the stress is the same everywhere, like when you pull on a rope. But often, it's not. Things like the shape of the building, how the weight is applied, and the materials used can make the stress uneven. This can create areas where the stress is much higher, which can weaken the building.

Engineers use special tools and techniques to see how these forces are spread throughout the building. This helps them design strong and safe structures by using the right materials in the right places. By understanding how the stress behaves, they can make sure the building can handle all kinds of forces without breaking.

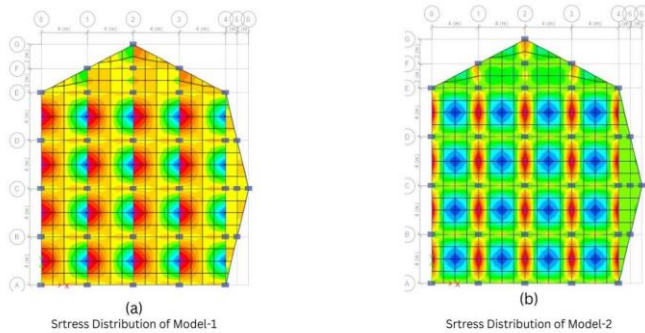


Figure-8: Stress Distribution of Model-1 and Model-2.

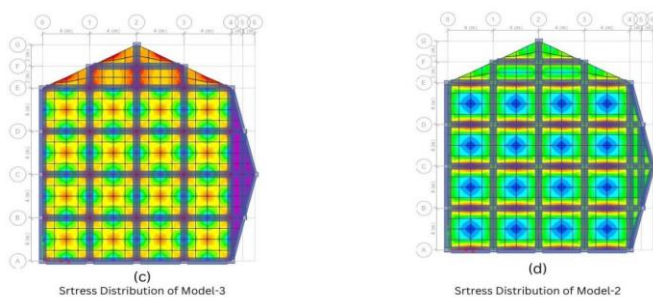


Figure-9: Stress Distribution of Model-3 and Model-4.

4. CONCLUSION

4.1. Conclusion

After analysis of result in research work of Soil Structure Interaction in Non Parallel System of Reinforced Concrete Frame Structure with CFST Column, the conclusion are given below based on the objective of this research work:

The value of the base shear is low in the model-01 where we have considered the RCF without SSI, the reason behind it that the value of the base shear is increasing as weight of structure increasing. Here weight of the models-03 is high because of the using CFST Column. So the value of the base shear is low at both load case EX as well as EY in the model-01.

As per Indian Standard Code, the value of natural period should be exist between 0.05 to 2.00 second for G+20 structure. As we can see that from table of the natural period all value is existing between them, and minimum value of the natural period in the model-03, and maximum in the model-01.

As we know that total height of the structure is 33250mm, so maximum storey displacement should not be greater than 133mm at top floor. As we can see that from table of the

storey displacement, all value is under 133mm that means all model is safe, but the minimum lateral displacement is in the model-03 and maximum in the model-01 at both load case EX as well as EY. After analyzing all result that, we found that model-03 is more suitable for the construction of the non parallel system with CFST Column. From graph of the stress distribution, we can see that maximum stress generating in the model-1. And in the model-3, maximum stress generating at the end of the non parallel of structure. Minimum value of the stress distribution is in the model-4.

4.2. Future Scope

In this research work, we have studied about the Soil Structure Interaction in Non Parallel System of Reinforced Concrete Frame Structure with CFST Column, and used the Dynamic Analysis for all four models. In the future, we can use Response Spectrum Analysis, and also can be used Wind Load form the IS Code 875 part-3. Also can be use for different grade for the material for enhancing the result at the sub structure

4.3. Limitation

There are several limitation of this research research, which are given below:

- Wind Load is not considered due to lack of the time.
- Using Dynamic Analysis used by using the Time History analysis in the ETABS Software.
- All result is only valid for the Non Parallel Structure, not for the parallel structure.
- This is not applicable for the static analysis of the any models.

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