SEISMIC PERFORMANCE OF OUTRIGGER SYSTEM IN HIGH RISE STRUCTURES UNDER SEISMIC LOADING

Dr. R. Saravanan[1], Dr. N. Pannirselvam[2*]
[1]Professor and Head, Department of Civil Engineering, Kings College of Engineering, Thanjavur, Tamil Nadu, India, saravanan.civil@kingsengg.edu.in
[2]Associate Professor, Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur, Tamil Nadu, 603203, India
** Corresponding Author Email: pannirsn@srmist.edu.in*

ABSTRACT
The development of high-rise buildings has always faced challenges. Many structural systems have been developed to reduce the lateral displacement of tall buildings. Outrigger system is commonly used to decrease both horizontal movement and the moment of the foundation to the structure. It is also used to improve the performance of high-rise structures under seismic loads. In this paper, seismic analysis of high rise building with outrigger system has been provided to understand the behaviour of high rise building in terms of maximum storey draft, maximum storey displacement and storey stiffness. Three analysis models 30, 40 and 50 storeys with different vertical elements were carried out to investigate and analyse for the gravity loading and seismic loading using ETABS software. A total of 18 buildings model are tested. To evaluate the optimum position of outrigger system, different stiffness cases also have been performed in structures to get the overall behaviour of the building. The shear wall outrigger without belt truss gives better result than beam outrigger with belt truss.

Keywords: ETABS, High-rise buildings, Lateral Load, Outrigger System.

Introduction

Nowadays, the high-rise buildings have become very common around the world. They could be solutions for population density problems and the lack of available space for development. The lateral loads are always considered as the main issue in high-rise structures. As the height of the structure increases, the effect of lateral forces also increases. The high-rise structures need proper structural system to resist those loads and to be designed as per required of a particular seismic zone. Outriggers system are commonly used for controlling the lateral displacement of tall buildings. Outriggers are basically consisting of beams, trusses or shear wall members that connect a core to an outer column, to reduce lateral displacement and increase lateral stiffness. The outriggers also reduce the overturning moment developed in the core shear wall and transmit the reduced moment to the external columns. Outriggers in a structure can be in different shapes like single or multiple according to the height of the building. They are combined with the belt trusses and shear bands to increase their quality of resisting lateral loads.

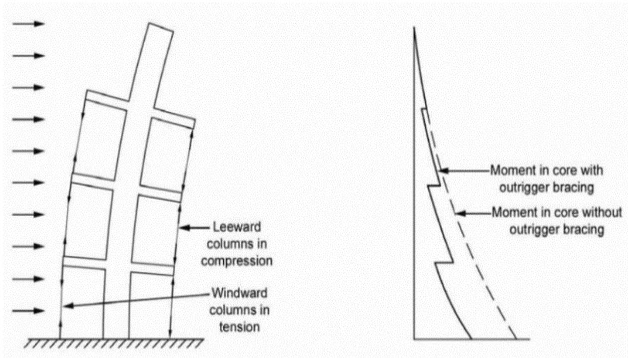

Figure 1 The effect of outrigger on moment (Source: Taranath 1998)

Authors modelled one to four numbers of outriggers in the building with different types using dynamic analysis for earthquake load to determine the optimum location. The results show that the concrete shear wall outriggers are more influential than steel outriggers and the increase of outriggers number provides more effective resistance of lateral loads [1]. Presented the optimum position of outriggers by analysing the structure using gradient-based nonlinear programming, which modelled outriggers with several cross-section areas to find the relation between outrigger stiffness and optimum location. The increase of dimension of outriggers leads to move the optimum location down [2]. Conducted analysis on structures with various high levels with different stiffness conditions using pushover analysis to realize the behaviour of structure for optimum position. The idealized influence of outrigger at the middle of the building for base shear and 0.3 of total high level for displacement were observed [3]. This study adopted a new case study by providing a steel belt outrigger on composite structures, single and double level steel belt outrigger with different prototypes which were carried out to account efficient position outrigger that reduces the lateral deflection. This study showed that three single-level outriggers in every third of the structures were more effective than double outrigger levels [4]. Another study proved that the outrigger stability behaviour found that there is a relation between stiffness and ultimate load capacity. In unsymmetrical outriggers, there is variable stiffness value with consideration stiffness under compression which is less than under tension. Using large sections of outriggers does not always mean increasing building performance [5]. Tavakoli studied the seismic performance of outrigger-braced system based on finite element and component-mode synthesis methods [6]. The optimal number of outriggers in a structure under different lateral loadings [7]. The behavior and design of distributed belt walls as virtual outriggers for concrete high-rise buildings [8]. The outrigger topology and behaviour and Optimum design method for simplified model of outrigger and ladder systems in tall buildings using genetic algorithm [9,10]. The safety analysis of optimal outriggers location in high-rise building structures and the progressive collapse analysis of a high-rise building considering the effect of an outrigger belt lateral load resisting system [11,12]. The effects in conventional Nonlinear static analysis with the evaluation of control node position [13]. The experimental study on the seismic behavior of a shear wall with concrete-filled steel tubular frames and a corrugated steel plate [14]. The practical approach for estimating the floor deformability in existing RC buildings: evaluation of the effects in the structural response and seismic fragility [15]. A single-run multi-mode pushover analysis to account for the effect of higher modes in estimating the seismic demands of tall buildings [16]. The floor acceleration demands in a twelve-storey RC shear wall building [17].

MATERIAL PROPERTIES AND GEOMETRIC SPECIFICATIONS

A case study of concrete buildings with 30, 40, and 50-storey was modelling with 3m of storey height is assumed since it is the general practice of the height of the building. The floor plan is a square of length 48m with 6 bays of 8m in both directions. The strength of concrete M40 and steel of Fe345 with column section size of 1.5m × 1.5m and the beam of section 1m × 0.5m, slab of thickness 0.3m. The core of the structure is square shear walls with 0.5 m cross-section.

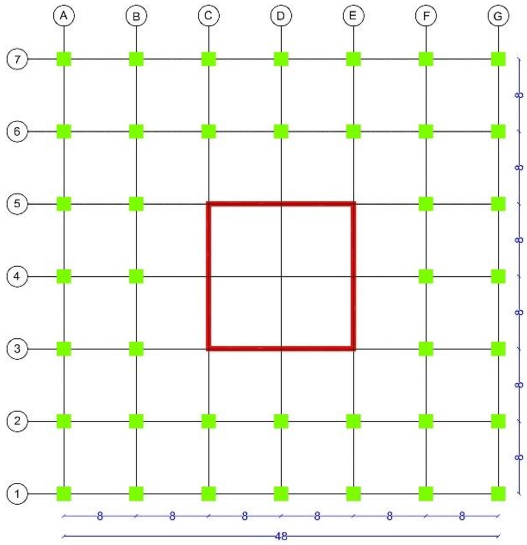

Figure 2 Floor plan of the structures (m)

Two types of outriggers are considered as the lateral force-resisting system, beam outrigger with belt truss and shear wall outriggers without belt truss. The loads calculated according to IS-456 -1893 (Part 1) and IS-875-1987 (Part 1), the dead load on the floor slab is 2 kN/m² and the live load on the floor slab is 3 kN/m². The seismic load was designed as per IS-1893-2016 with seismic zone as III. The parameters considered in this study are storey displacement, storey drift, and storey stiffness. The vertical, horizontal and longitudinal loads are considered. The structures are designed and checked under gravity and earthquake loads.

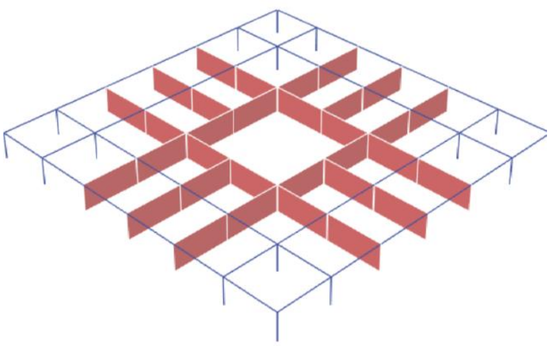

Figure 3 Shear wall outrigger without belt truss

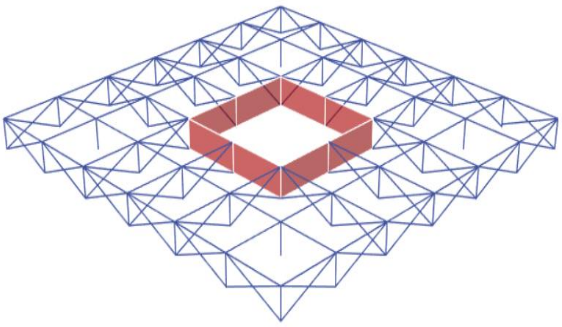

Figure 4 Beams outrigger with belt truss

MODELING AND ANALYTICAL INVESTIGATIONS

The overall seismic evaluation of 18 models was carried out using ETABS software for the cases given below:

Case 1: 30 storey building with shear wall core with different types of outriggers:

- Core wall only
- Core wall with one beam trusses outrigger at 0.5H of the total storey
- Core wall with one shear wall outrigger at 0.5H of the total storey
- Core wall with two beam trusses outriggers at 0.3H and 0.6H of the total storey
- Core wall with two shear wall outriggers at 0.3H and 0.6H of the total storey

Case 2: 40 storey building with shear wall core with different types of outriggers:

- Core wall only
- Core wall with one beam trusses outrigger at 0.5H of the total storey
- Core wall with one shear wall outrigger at 0.5H of the total storey
- Core wall with two beam trusses outriggers at 0.3H and 0.6H of the total storey
- Core wall with two shear wall outriggers at 0.3H and 0.6H of the total storey
- Core wall with three beam trusses outriggers at 0.25H, 0.5H and 0.75 H of the total storey
- Core wall with three shear wall outriggers at 0.25H, 0.5H and 0.75 H of the total storey

Case 3: 50 storey building with shear wall core with different types of outriggers:

- Core wall with one beam trusses outrigger at 0.5H of the total storey
- Core wall with one shear wall outrigger at 0.5H of the total storey
- Core wall with two beam trusses outriggers at 0.3H and 0.6H of the total storey
- Core wall with two shear wall outriggers at 0.3H and 0.6H of the total storey
- Core wall with three beam trusses outriggers at 0.25H, 0.5H and 0.75 H of the total storey
- Core wall with three shear wall outriggers at 0.25H, 0.5H and 0.75 H of the total storey

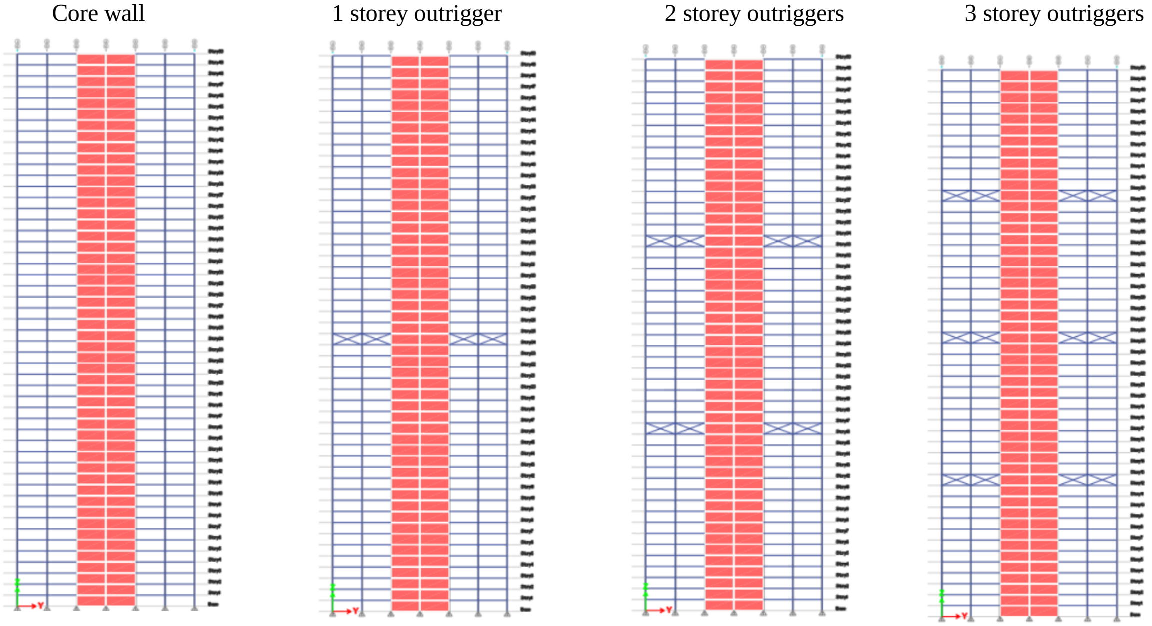

Figure 5 A longitudinal section showing the distribution of outriggers in all cases

RESULTS AND DISCUSSION

1. Results for case1 of 30 storey building with shear wall core with different types of outriggers.

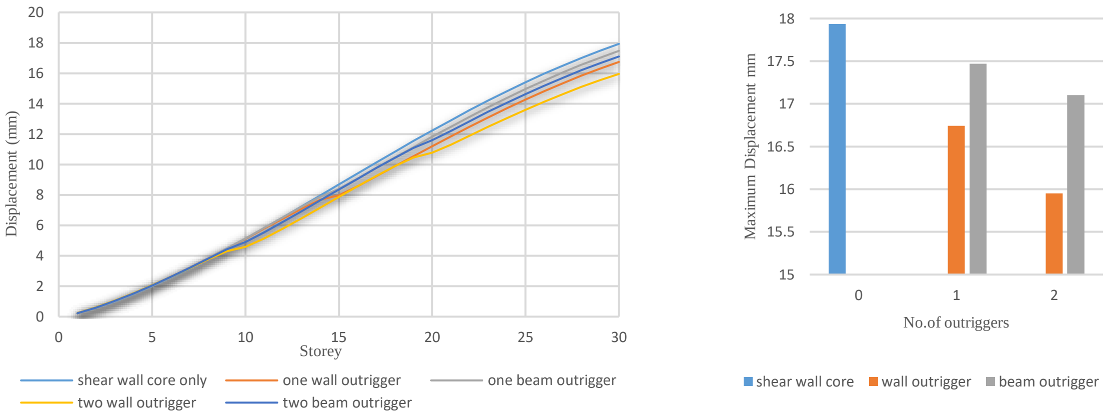

Figure 6 Storey displacement Comparison for case 1

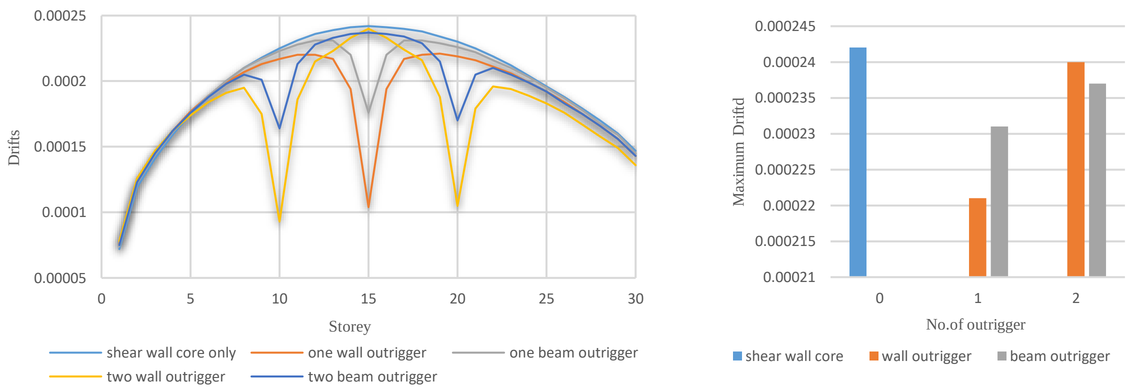

Figure 7 Storey drifts comparison for case1

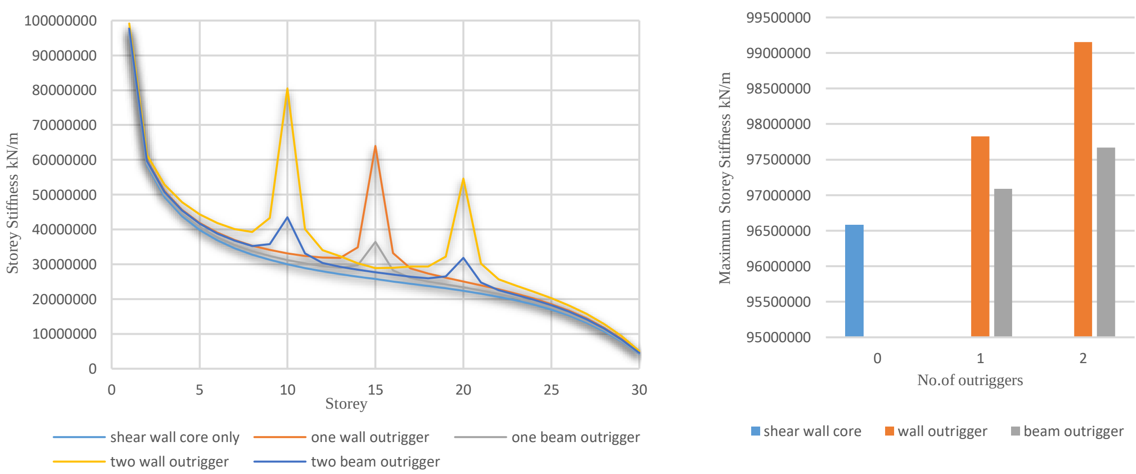

Figure 8 Storey stiffness comparison for case 1

2. Results for case 2 of 40 storey building with shear wall core with different types of outriggers

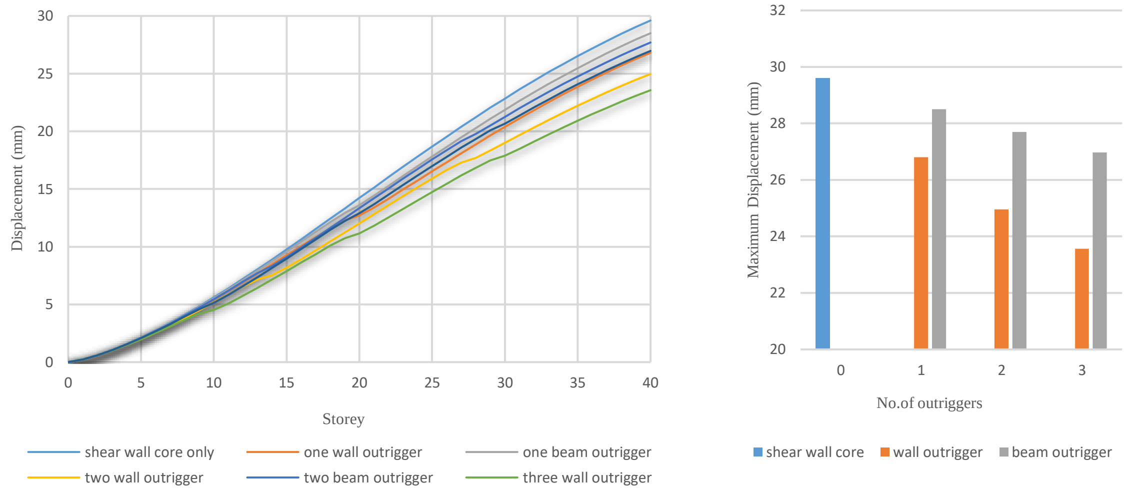

Figure 9 Storey displacement Comparison for case 2

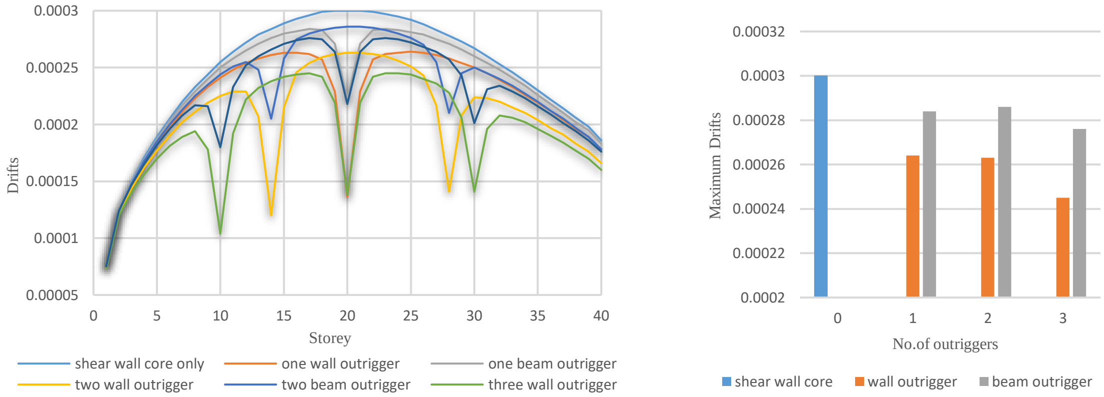

Figure 10 Storey drifts comparison for case 2

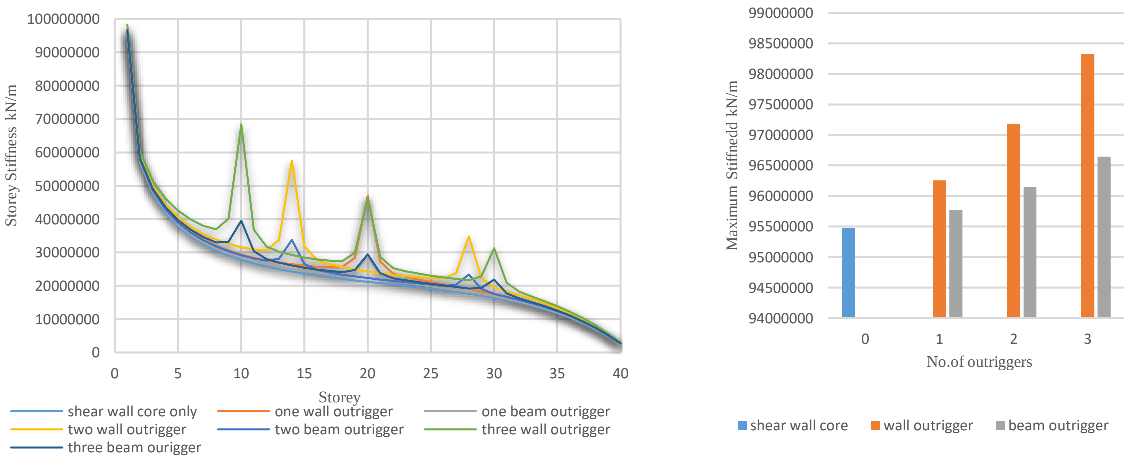

Figure 11 Storey stiffness comparison for case 2

3. Results for case of 40 storey building with shear wall core with different types of outriggers

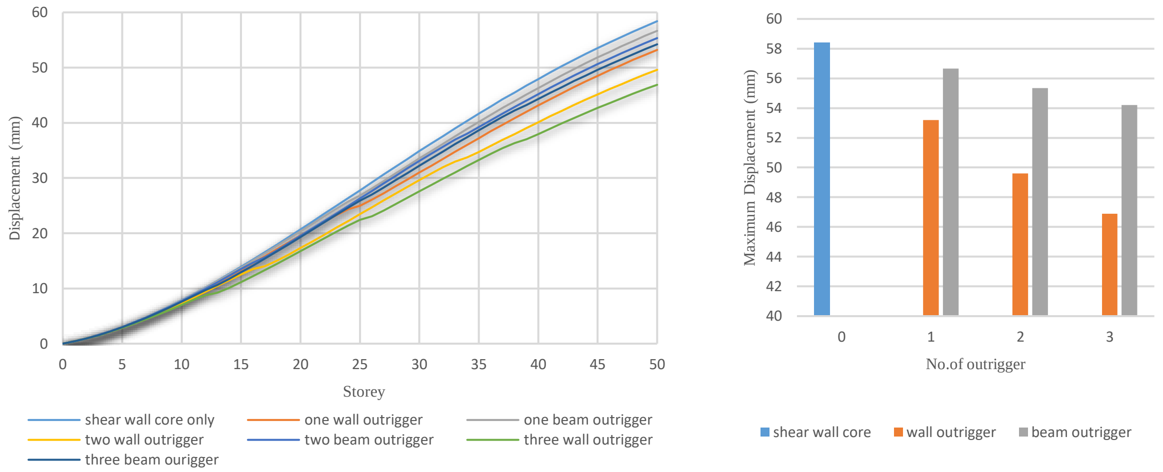

Figure 12 Storey displacement Comparison for case 3

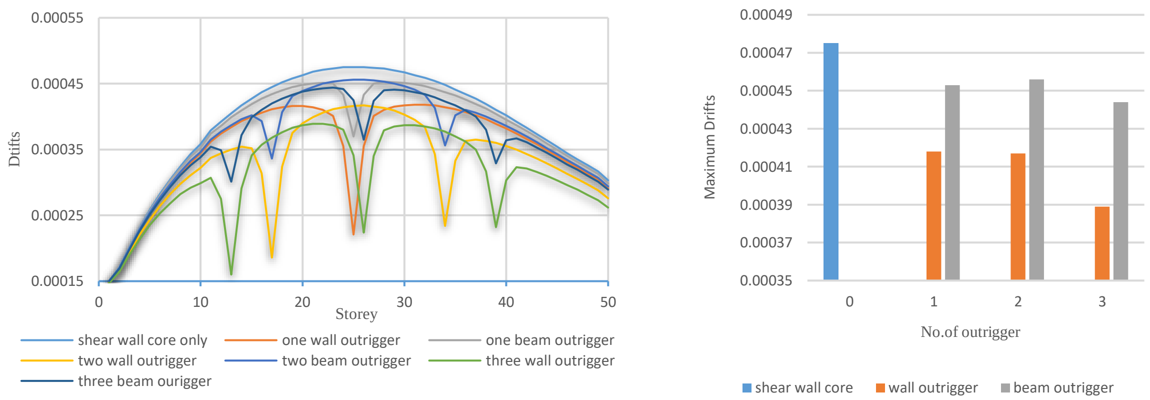

Figure 13 Storey drifts comparison for case 3

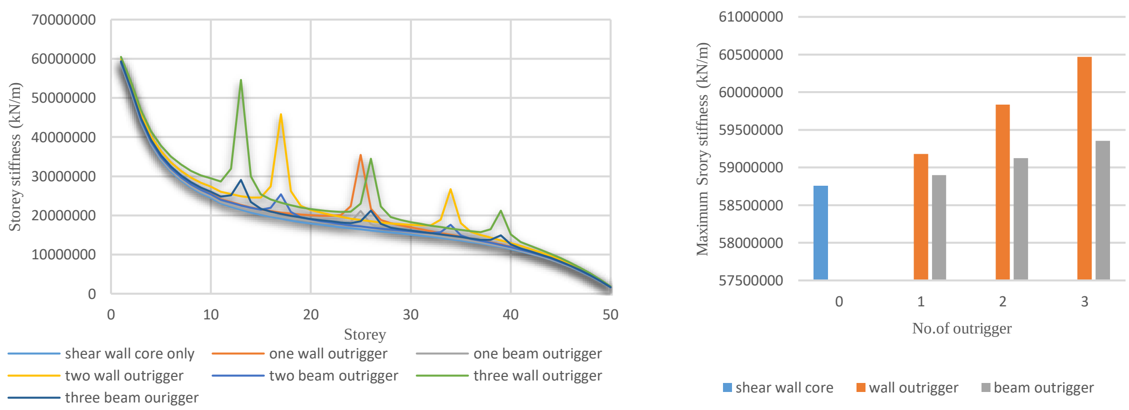

Figure 14 Storey stiffness comparison for case 3

CONCLUSION

In this study, seismic analysis of high rise building with outrigger system has been provided to understand the behaviour of high rise building in terms of maximum storey draft, maximum storey displacement, and storey shear. Three analysis models 30, 40 and 50 storeys with different vertical elements were carried out to investigate and analyse for the gravity loading and seismic loading using ETABS software. The results and conclusion are as follows:

- Storey displacement
  - In case1 the shear wall outriggers give the best result which decreases the storey displacement 11% instead of 5% for beams outriggers.
  - In case 2 the reduction reaches 20% for shear wall outrigger and 9% for beams outriggers.
  - In case 3 wall outrigger give the same result in case 2 but beams outriggers give 7%.
- In all cases using an outrigger system reduce the storey drifts with a slight preference for wall outrigger and with an increase in the number of outriggers the result became almost the same.
- The addition in the number of outriggers lead to an increase in the stiffness of the structure with stated that the stiffness of shear wall outrigger higher than beam outrigger.
- It’s obvious that using the outrigger system in high rise buildings can reduce the lateral deflection significantly.
- Using shear wall outrigger without belt truss gives better displacement and drifts but higher stiffness than beam outrigger with belt truss.

Statements and Declarations

Competing Interests:

No financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

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Compliance with ethical standard

Conflict of interest

We declare that all authors have no any potential conflict of interest including financial and personal or other relationships with other people or organizations.

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