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Seismic Response Prediction For Practical Tall Buildings Using Decoupling and Artificial Neural Network ANN

Master of science in structural engineering

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JAN, 2026

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Introduction

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- Today, I'll be presenting a study that applies advanced machine learning techniques specifically Artificial Neural Networks and Long Short-Term Memory models to predict the seismic response of tall buildings. Due to the complexity and high computational demands of seismic analysis, this research introduces a novel approach where each degree of freedom in a building is modeled using a dedicated neural network. This method, supported by a genetic algorithm for network optimization, has been tested on buildings up to 60 floors.
- The results closely match traditional structural analysis, offering a more efficient and scalable solution for seismic prediction in high-rise structures.

Thesis objective

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- Artificial Neural Networks (ANNs) continue to face significant challenges in accurately predicting the seismic response of tall buildings due to the increasing complexity of structural behavior under ground motion. This research aims to overcome these limitations by leveraging advanced machine learning techniques—specifically Long Short-Term Memory (LSTM) networks—to enhance prediction accuracy and computational efficiency.

- Traditional modeling methods are often time-consuming and computationally intensive. In contrast, this study proposes a novel approach that utilizes LSTM networks to streamline the prediction process by capturing the temporal dependencies of seismic input and structural response data.

Methodology

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- A decoupling strategy where in each degree of freedom (DOF) of a structure is modeled using a dedicated ANN. Consequently, a building with n floors will be represented by 3n independent ANNs, accounting for three translational DOFs per floor. This modular approach allows for parallel processing and scalability, facilitating more manageable and precise modeling of complex structural behaviors.
- The implementation leverages LSTM networks to capture temporal dependencies inherent in seismic data, thereby improving the prediction of structural displacements over time. This technique demonstrates the potential to streamline the seismic response prediction process, offering a viable alternative to conventional modeling methods.

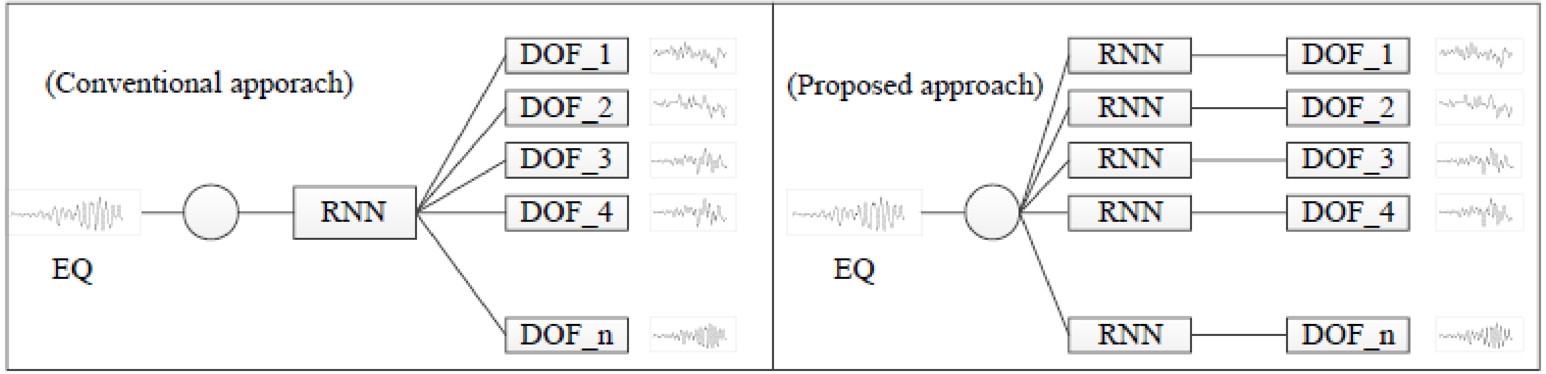

Fig. 1: **Conventional approach and proposed approach**.

Methodology

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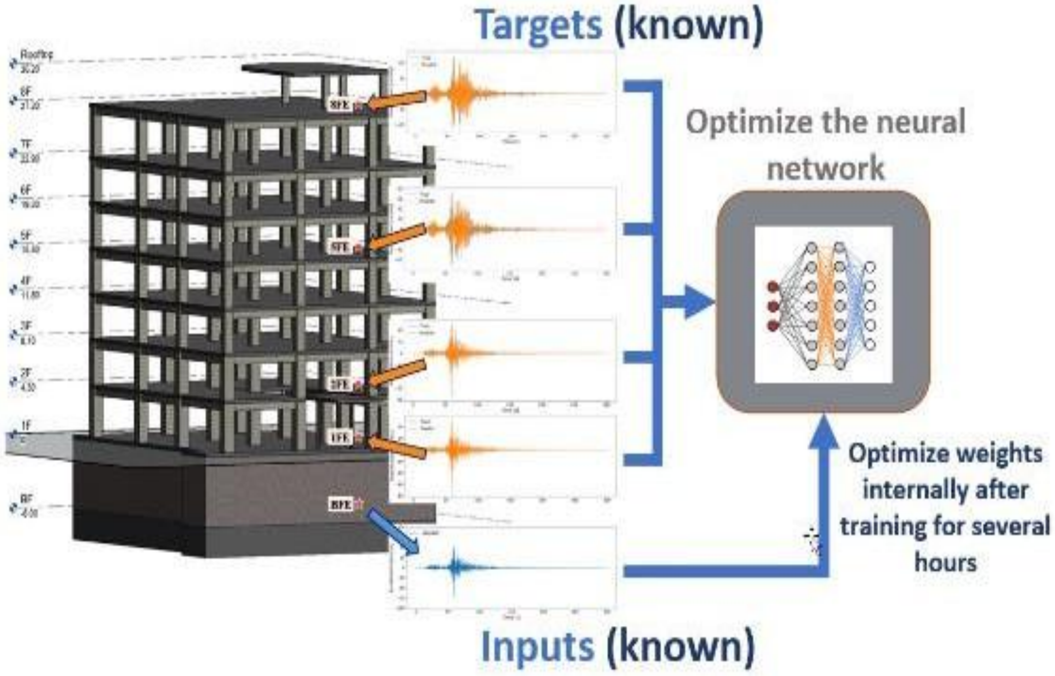
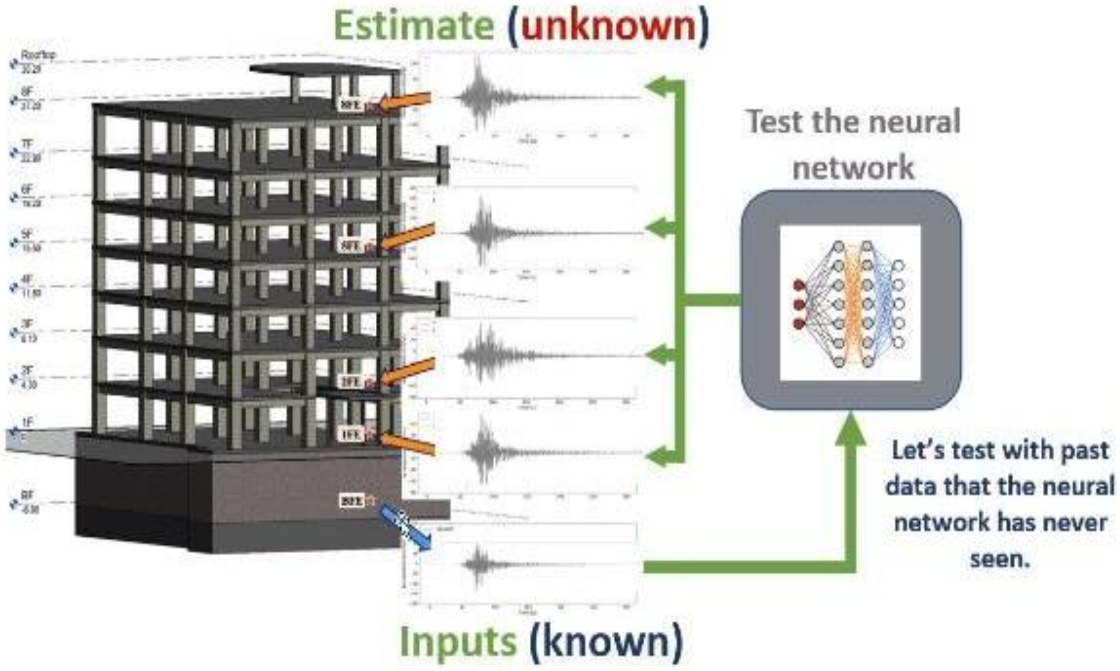
To predict seismic response using Artificial Neural Networks (ANNs), follow these steps:

1. Data collection: seismic inputs & responses.
2. ANN architecture design.
3. Train model on earthquake data.
4. Optimize using genetic algorithm.
5. Validate predictions on unseen data.





Practical Implementation

- In contrast to many previous studies that mainly relied on theoretical models, this research employs three real-life tall buildings to assess the performance of the proposed LSTM-based seismic prediction model. These structures vary in their structural configurations and are subjected to different seismic excitations for both training and validation phases.

- To represent a range of building heights, a typical floor plan is replicated 10, 20, 40, and 60 times, corresponding to structures of increasing height. Each floor is assumed to have a uniform height of 3.0 meters.

- Before proceeding with the predictive modeling, a verification process is conducted by comparing results from the Finite Element Method (using ETABS) with those from the Boundary Element Method (using PLPAK), ensuring the accuracy and consistency of the structural modeling approaches.

Practical Implementation

I. Modeling for practical buildings

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❑ The first tall building

In this example, a rectangular slab with overall dimensions of approximately 30 m × 22.6 m is considered. The slab is supported by several columns distributed symmetrically throughout the structure. Each column appears to be part of a repeated modular system.

- <u>Consist of:</u>

i. 33 Columns

ii. 5 Cores

iii. Area about 1592 m^2

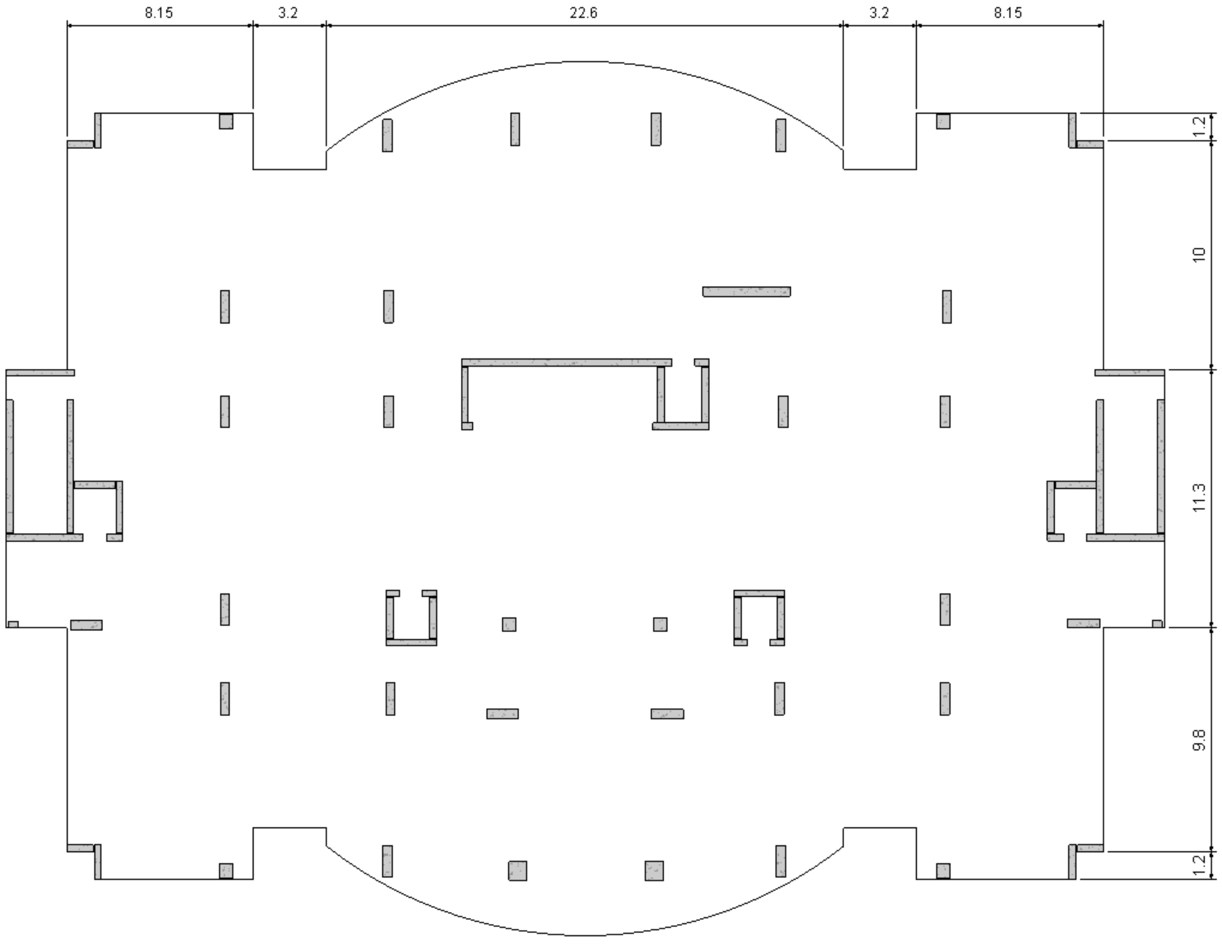

Fig. 1 **Layout plan for 1ST building**

Practical Implementation

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I. Modeling for practical buildings

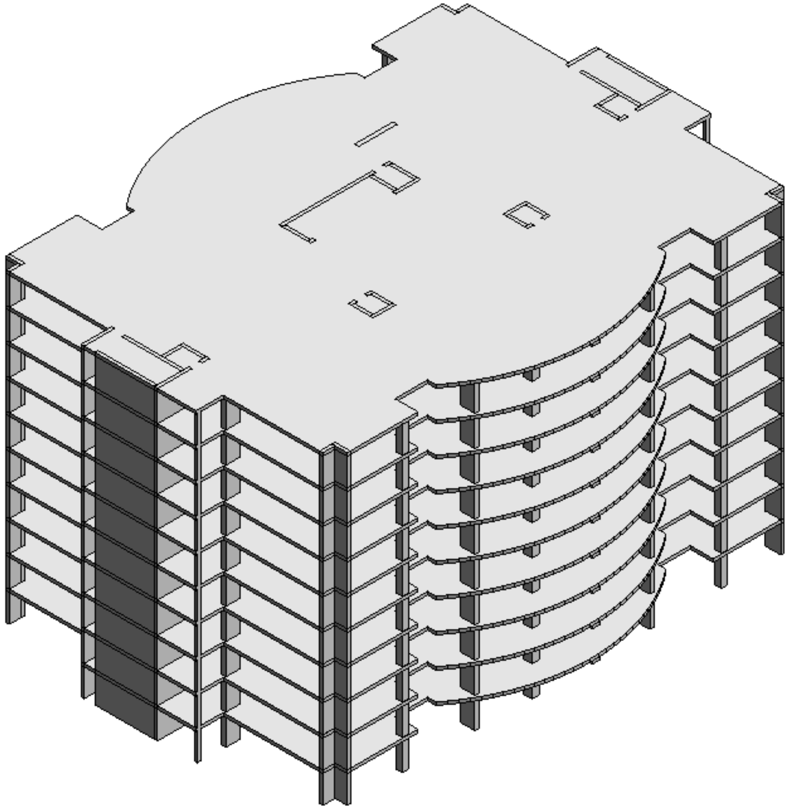

Fig. 2 **(10-story 3D for 1st building)**

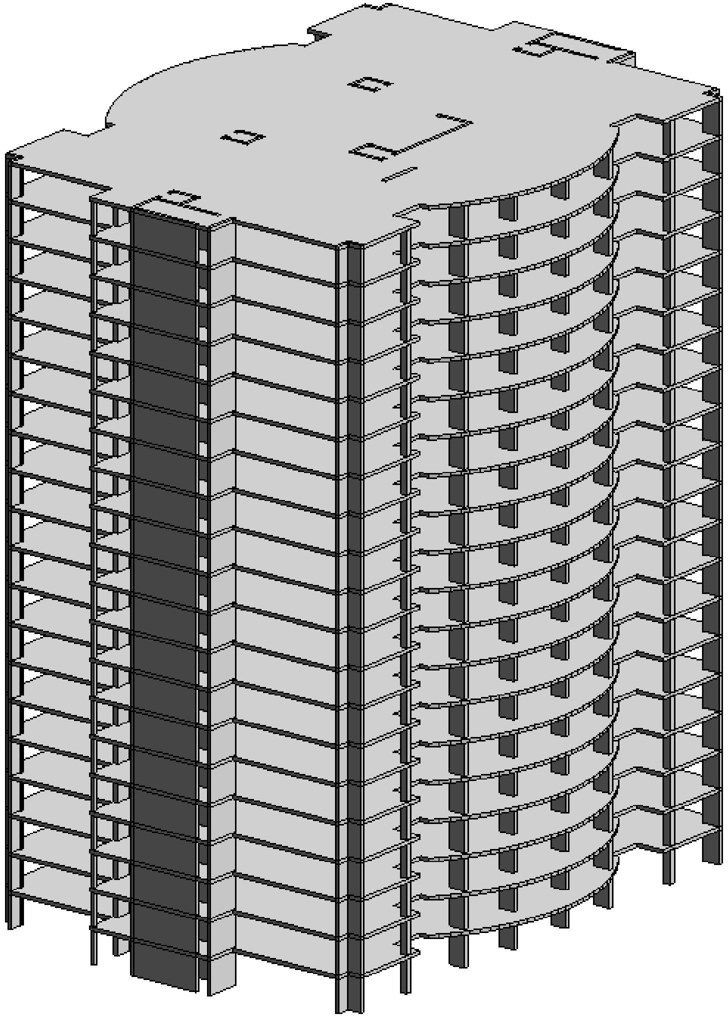

Fig. 3 **(20-story 3D for 1st building)**

Practical Implementation

I. Modeling for practical buildings

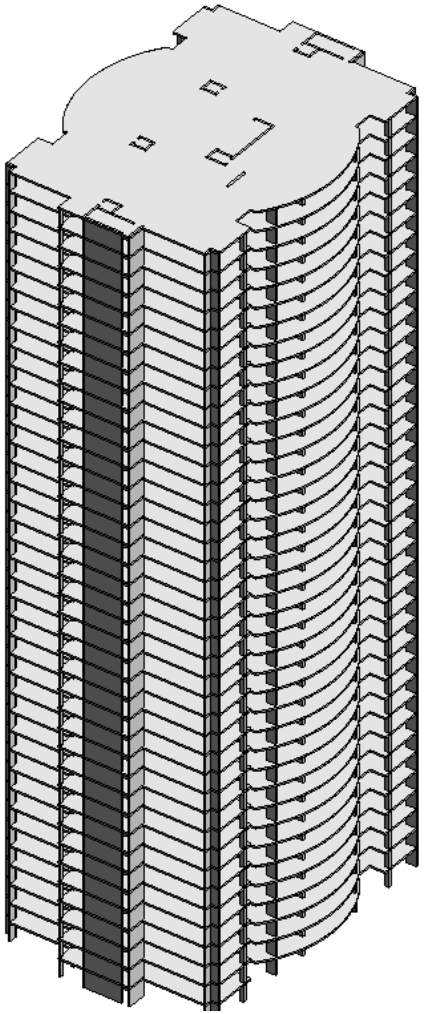

Fig. 4 **(40-story 3D for 1ST building)**

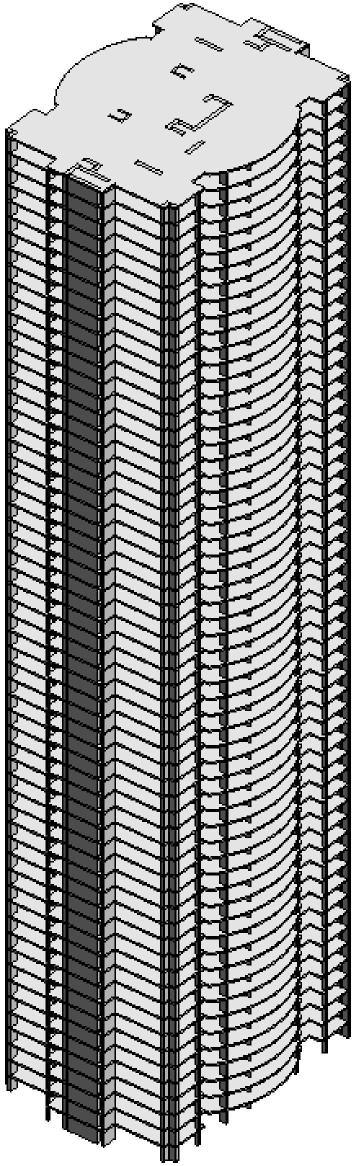

Fig. 5 **(60-story 3D for 1ST building)**

Practical Implementation

I. Modeling for practical buildings

❑ The second tall building

In this example, a slab of irregular "double-curved" geometry with overall dimensions of 60.95 m × 30 m is considered. The slab is supported on multiple rectangular columns grouped into central core zones and peripheral supports. Column groups in the middle support potential core walls, while outer columns support the rest of the slab symmetrically.

- <u>Consist of:</u>

i. 21 Columns

ii. 4 Cores

iii. Area about 1442 m^2

Fig. 6 **Layout plan for 2ND building**

Practical Implementation

I. Modeling for practical buildings

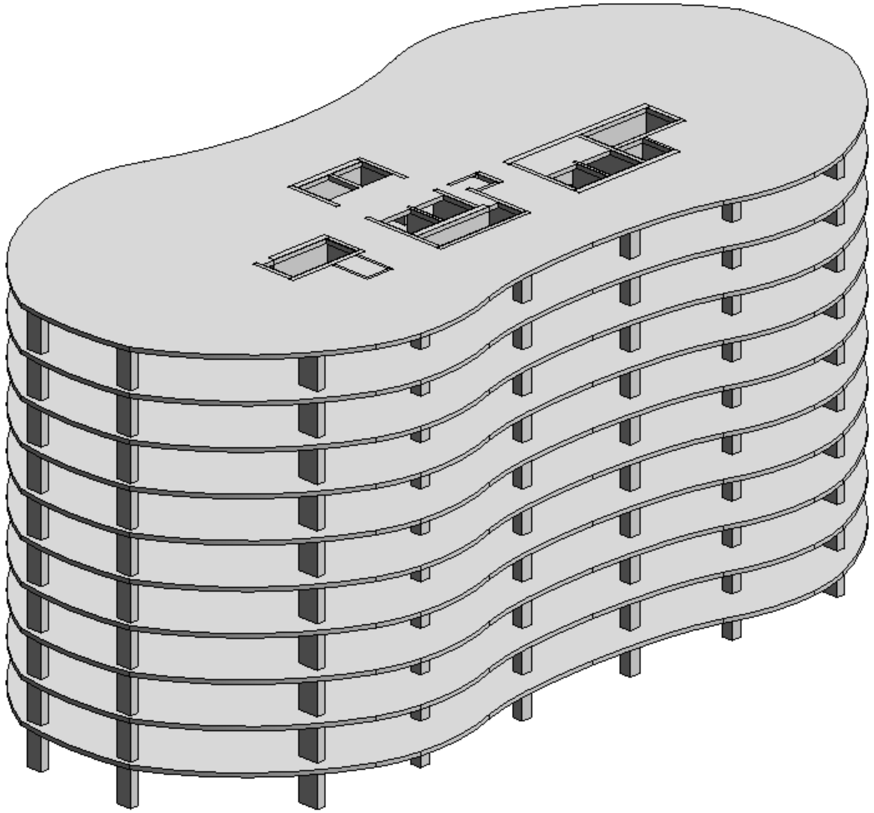

Fig. 7 **(10-story 3D for 2ND building)**

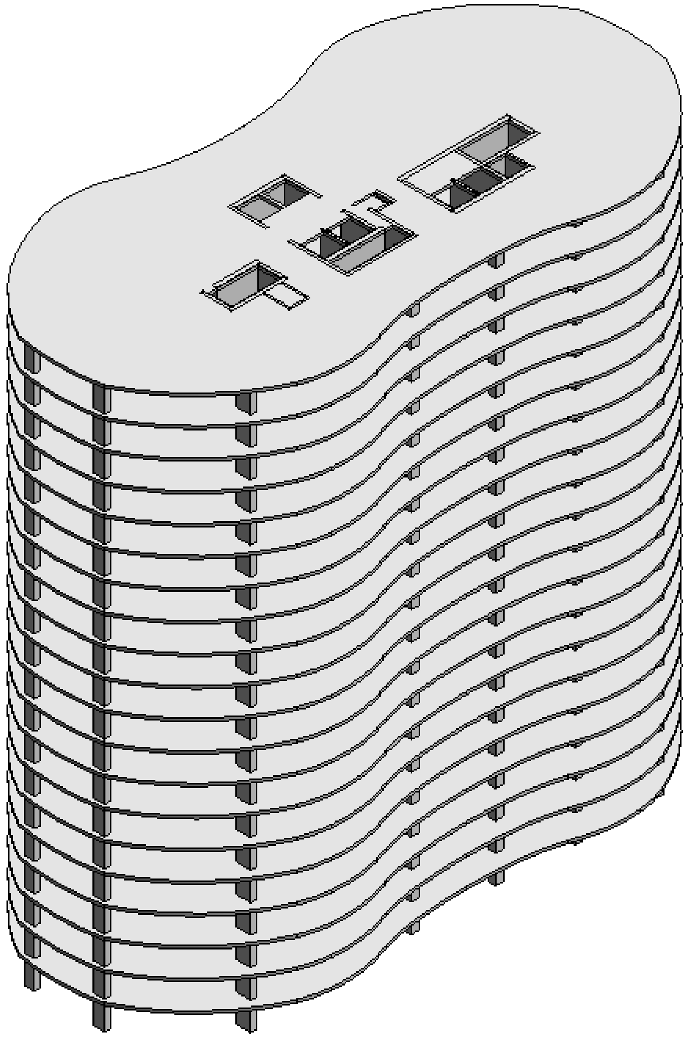

Fig. 8 **(20-story 3D for 2ND building)**

Practical Implementation

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I. Modeling for practical buildings

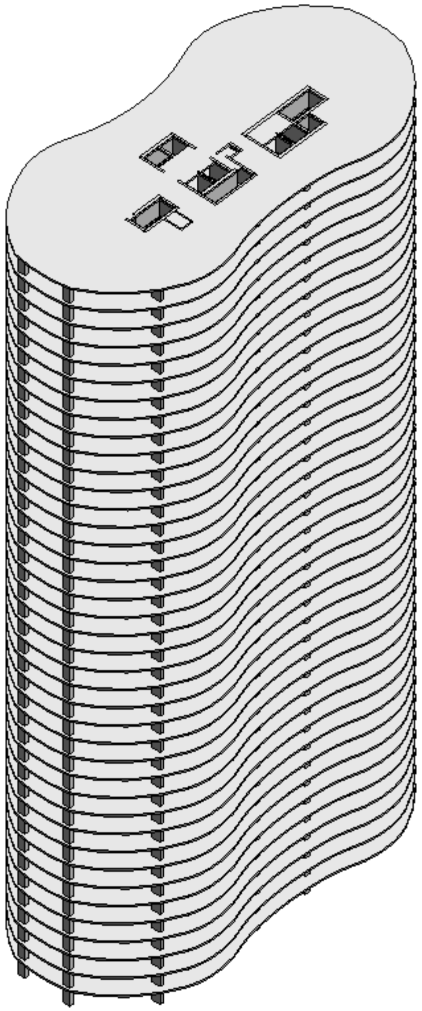

Fig. 9 **(40-story 3D for 2^{ND} building)**

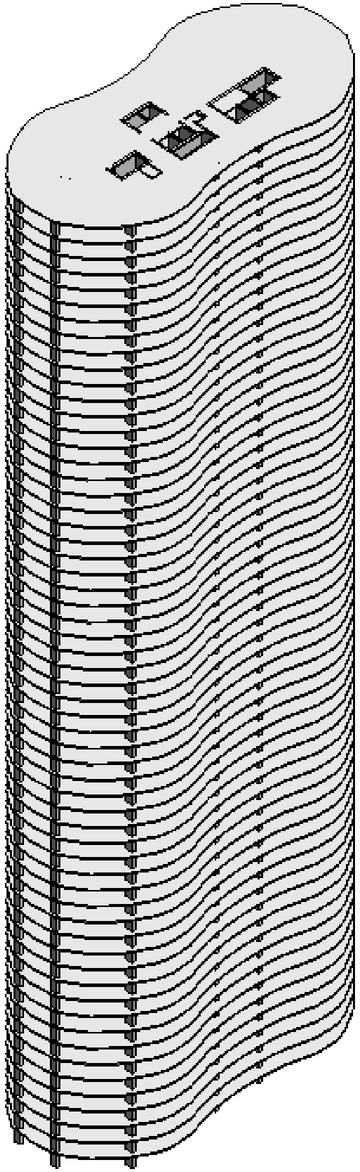

Fig. 10 (**60-story 3D for 2^{ND} building)**

Practical Implementation

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I. Modeling for practical buildings

❑ The third tall building

In this example, a rectangular slab of overall dimensions 44 m × 20 m is considered. The slab is supported on a system of regularly distributed square columns along the perimeter and interior zones. Additional groups of columns are concentrated at the center, forming core areas that may accommodate staircases, elevators, or service shafts.

- Consist of:

i. 21 Columns

ii. 2 Cores

iii. Area about 816 m^2

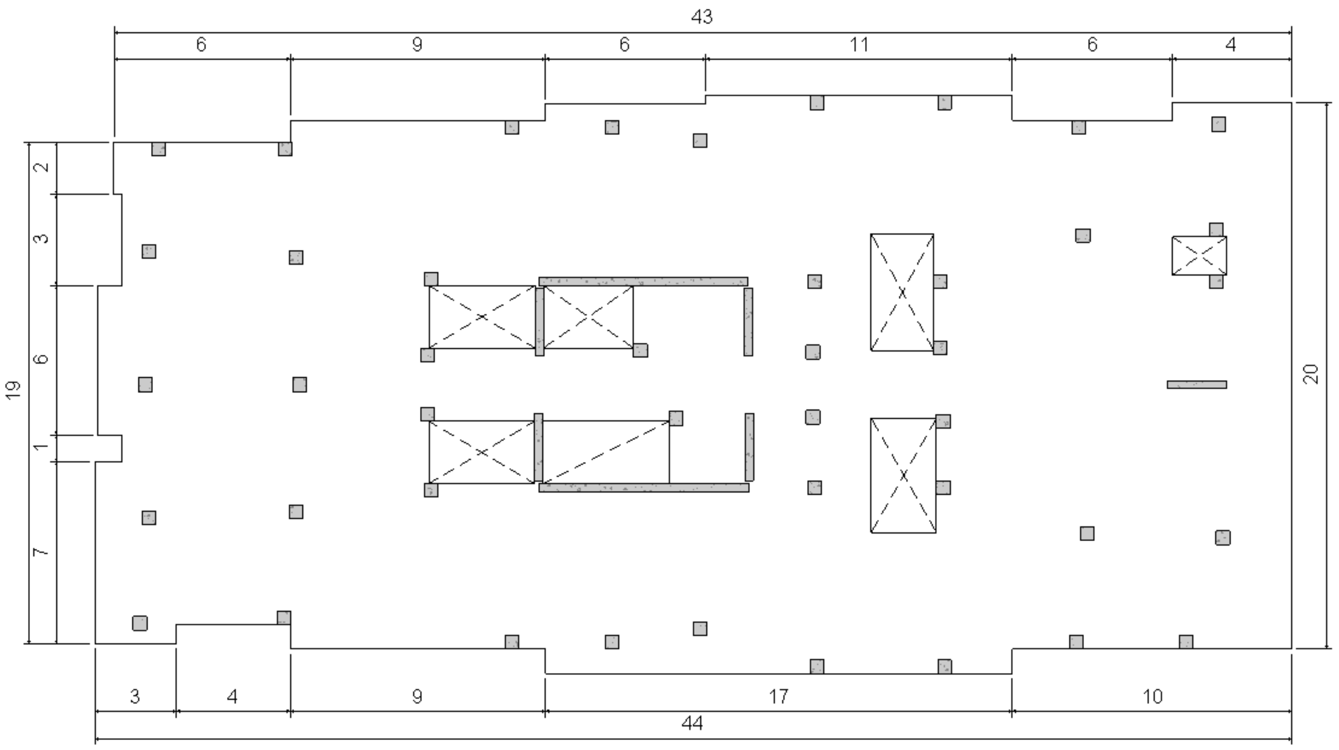

Fig. 11 **Layout plan for 3RD building**

Practical Implementation

I. Modeling for practical buildings

❑ The third tall building

According to high-rise building design principles, the height-to-width ratio (slenderness ratio) plays a critical role in structural stability and serviceability. For the studied building, the plan dimensions are approximately 44 m × 20 m, with the smaller dimension (20 m) controlling the lateral stiffness. Increasing the number of stories beyond 40 would result in a total height exceeding 120–130 m, which corresponds to a height-to-width ratio (H/B) greater than 6.

Therefore, to avoid slenderness-related issues and ensure compliance with serviceability and stability requirements, the building height in this study is limited to 40 stories.

Practical Implementation

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I. Modeling for practical buildings

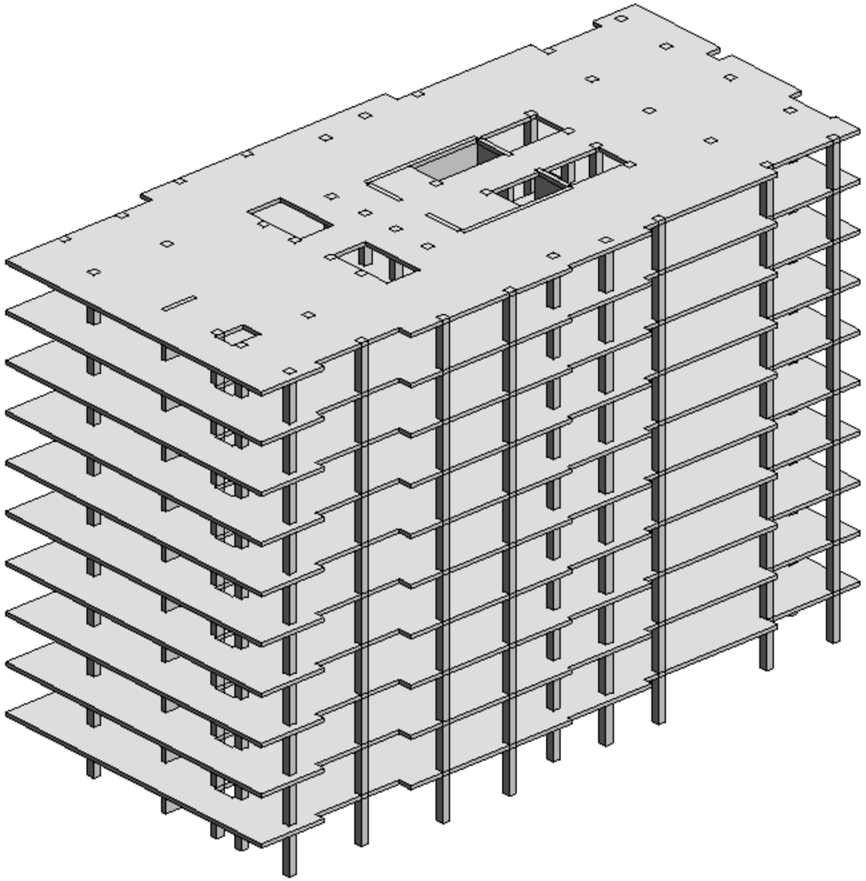

Fig. 12 **(10-story 3D for 3RD building)**

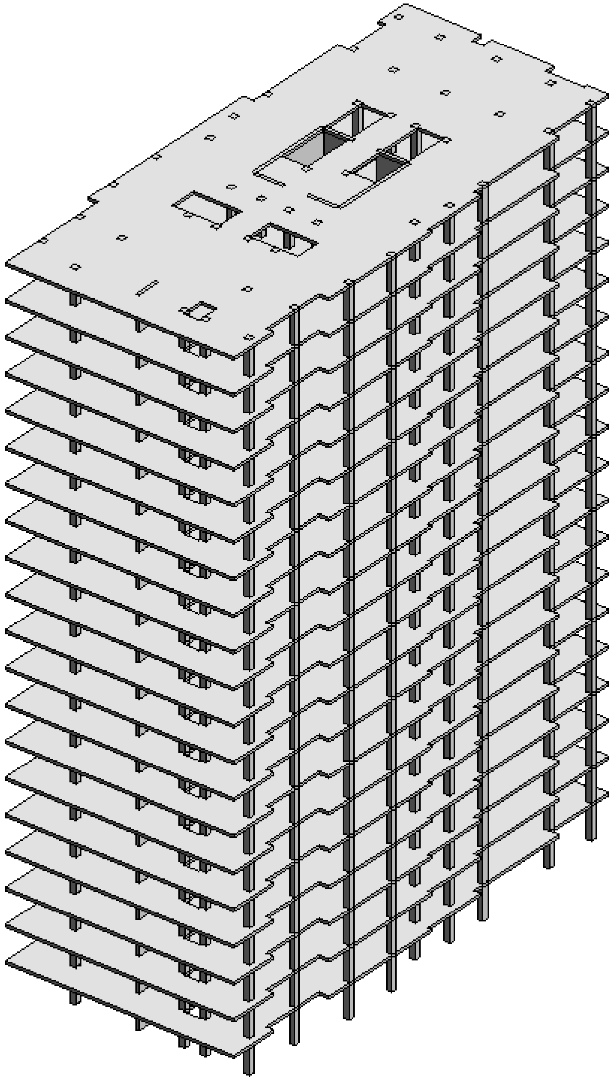

Fig. 13 (**20-story 3D for 3RD building)**

Practical Implementation

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I. Modeling for practical buildings

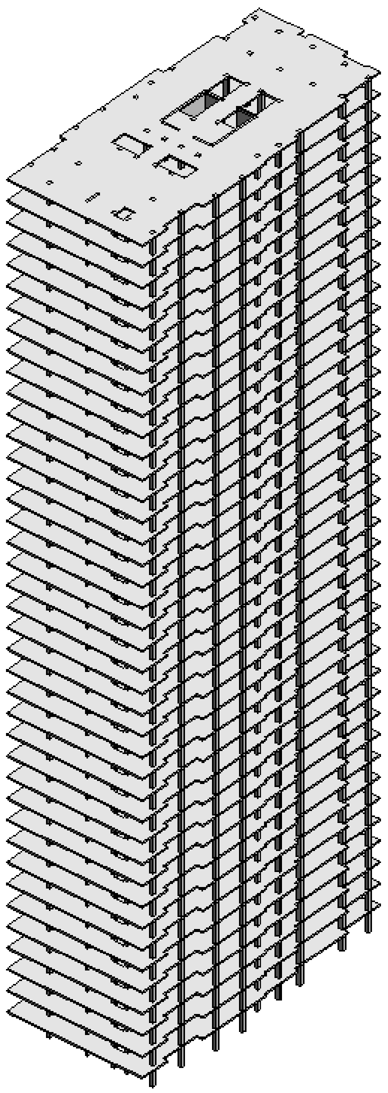

Fig. 14 (**40-story 3D for 3RD building)**

Practical Implementation

ii- Verification

- Compare ETABS (FEM) vs. PLPAK (BEM).

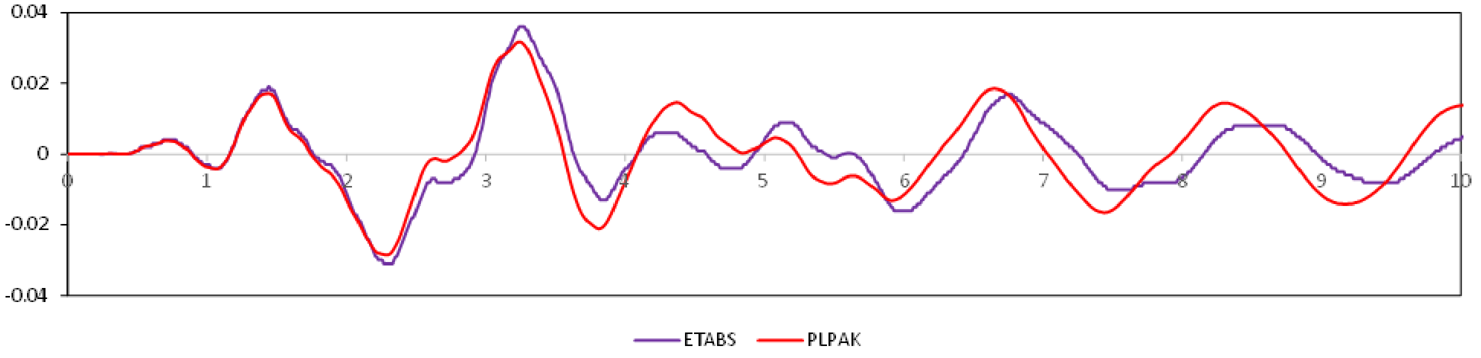

Fig. 15 ((**REAL DIMENSIONS)**

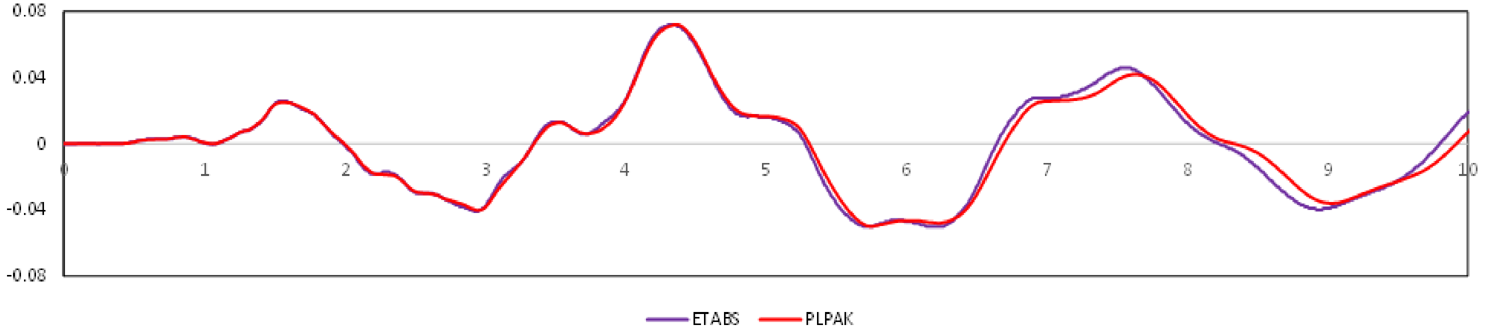

Fig. 16 (**100 mm DIMENSIONS)**

"We used PLPAK because it gave more accurate results, making our training and validation data more reliable."

Practical Implementation

iii- Training generated data

- The training earthquake history which is used for All buildings _Building 1,2&3_from 10-store up to 60-store is artificial earthquake which consists of (14770) step and time step between point 0.01 (sec) as shown in (Fig.18).

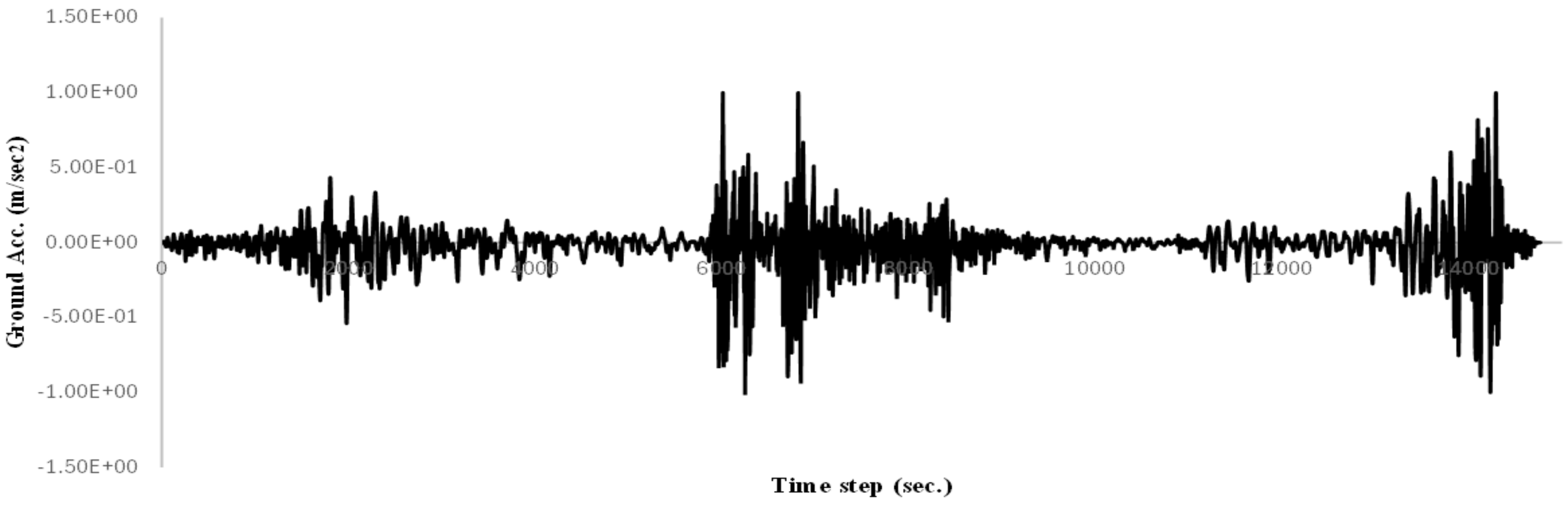

Fig. 18 **Training Data for stories above 20-story**

Practical Implementation

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iv- Validation generated data

- The validation earthquake history which is used for All buildings _Building 1,2&3_from 10-store up to 60-store is artificial earthquake which consists of (5800) step and time step between point 0.01 (sec) as shown in (Fig.19).

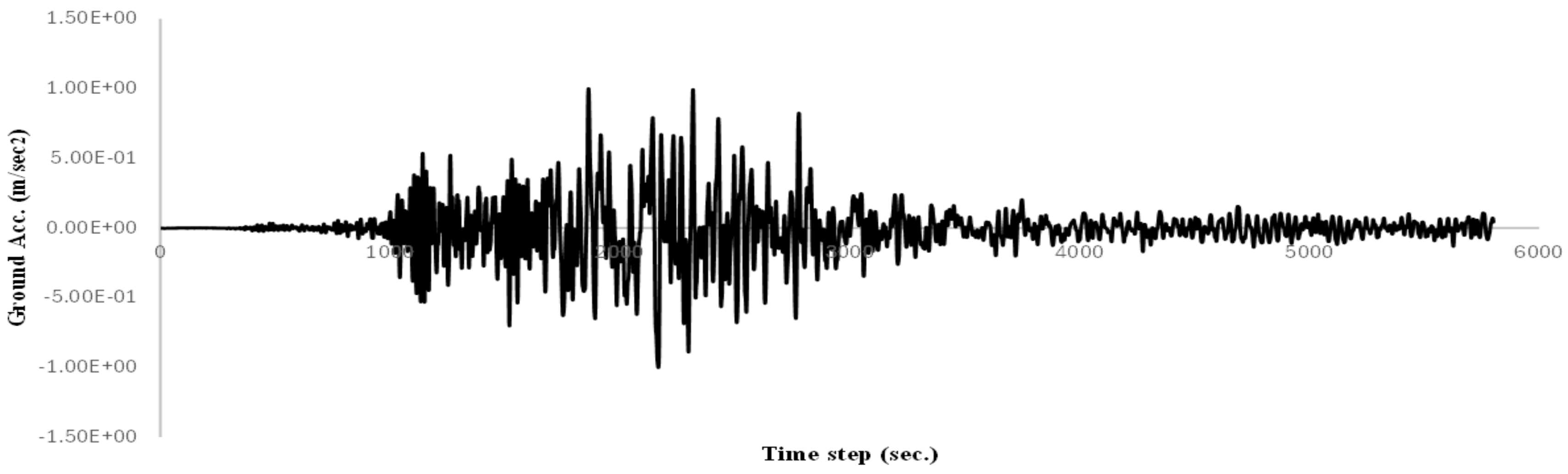

Fig. 19 **Validation Data EQ-92**

Practical Implementation

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v- Testing generated data

- The Testing earthquake history which is used for All buildings _Building 1,2&3_from 10-store up to 40-store is EQ-Aqaba 1995 and Turkey 2023 which consists of (12000, 12500) Point and Time step between point 0.01 (sec) as shown in (Fig.20).

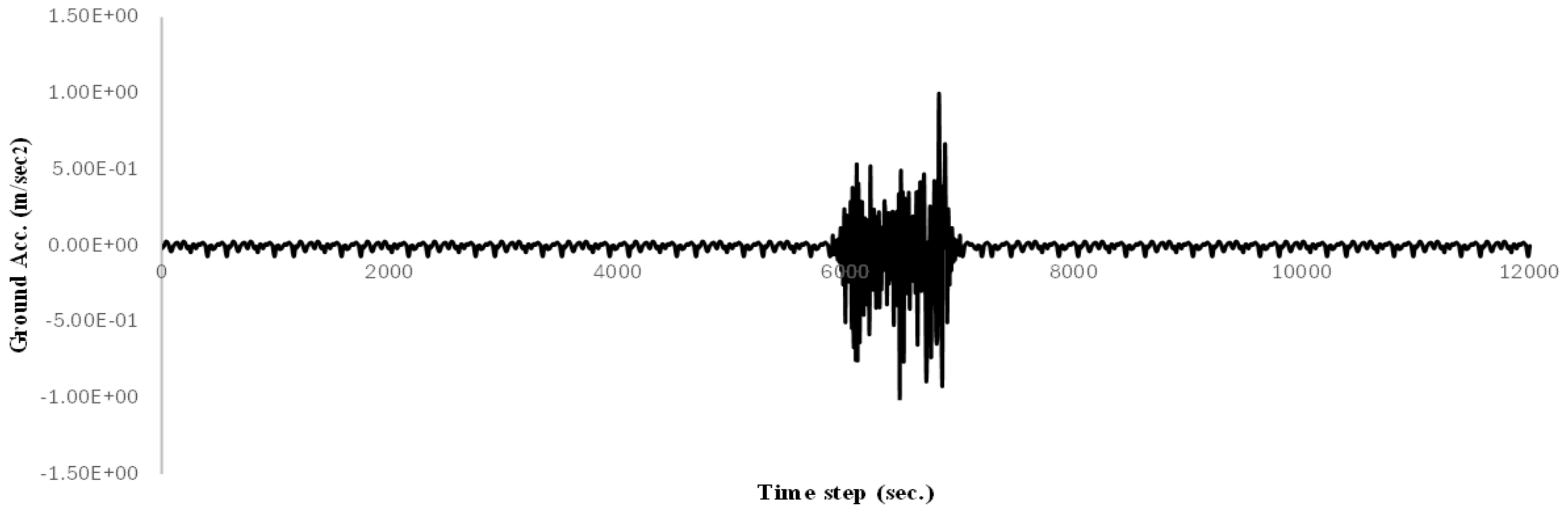

Fig. 20 **Testing Data EQ-Aqaba**

Practical Implementation

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v- Testing generated data

- The Testing earthquake history which is used for All buildings _Building 1,2&3_from 10-store up to 40-store is EQ-Aqaba 1995 and Turkey 2023 which consists of (12000, 12500) Point and Time step between point 0.01 (sec) as shown in (Fig.20& 21).

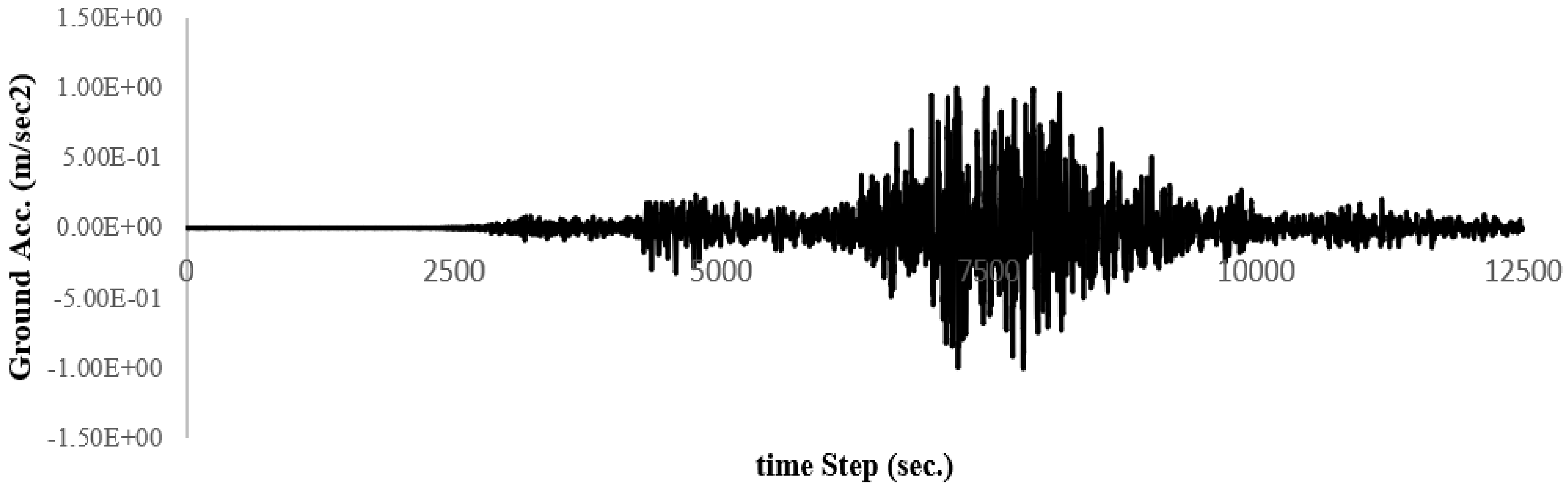

Fig. 21 **Testing Data EQ-Turkey 2023**

Results

❑ The first tall building consists of 10 – stories

- **Aqaba Earthquake-1995**

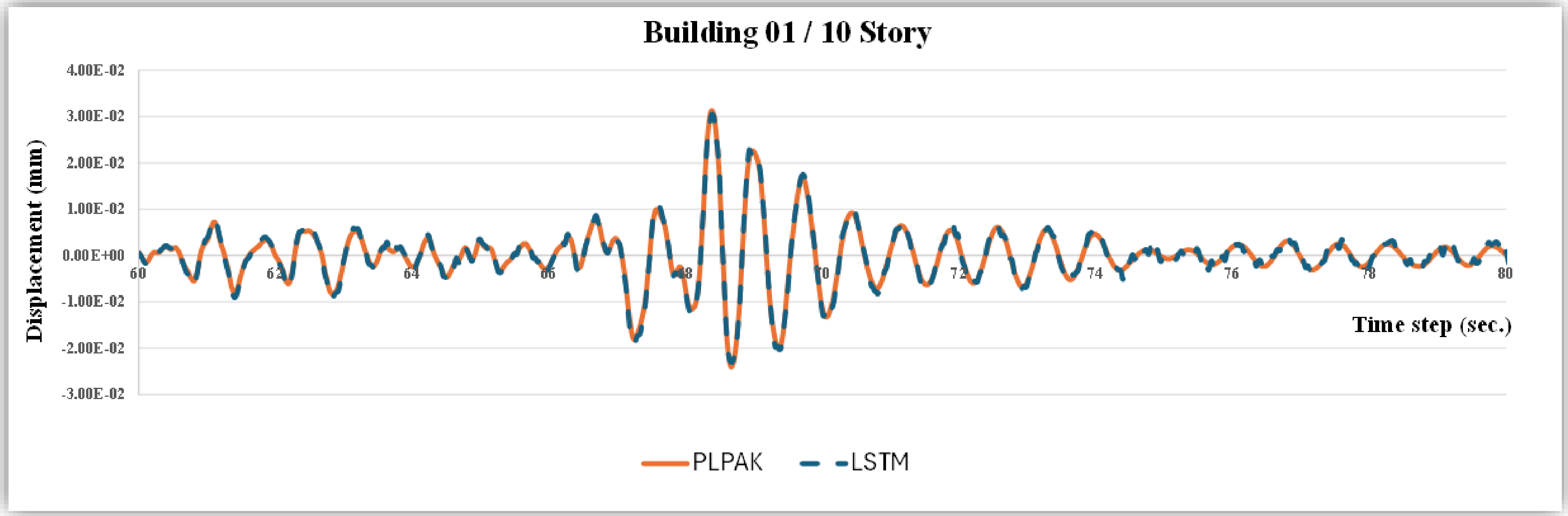

Fig. 21 **Displacement for 1ST building 10-Story**

Results

❑ The first tall building consists of 10 – stories

- **Turkey Earthquake-2023**

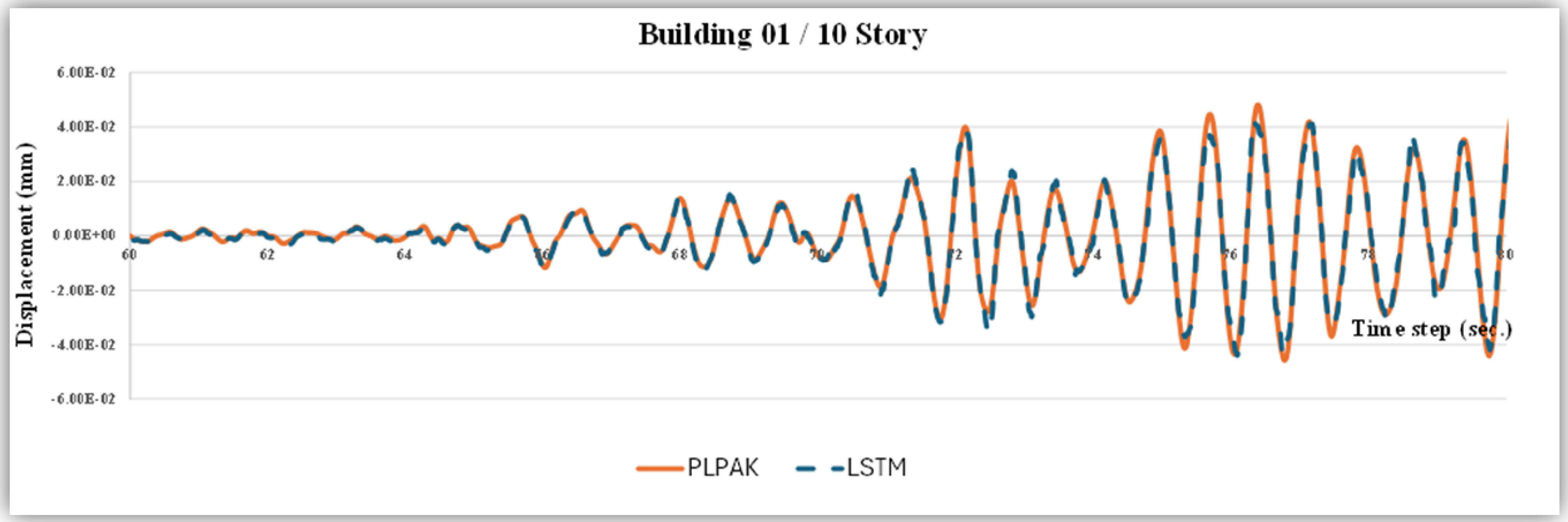

Fig. 21 **Displacement for 1ST building 10-Story**

Results

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❑ The first tall building consists of 20 – stories

- **Aqaba Earthquake-1995**

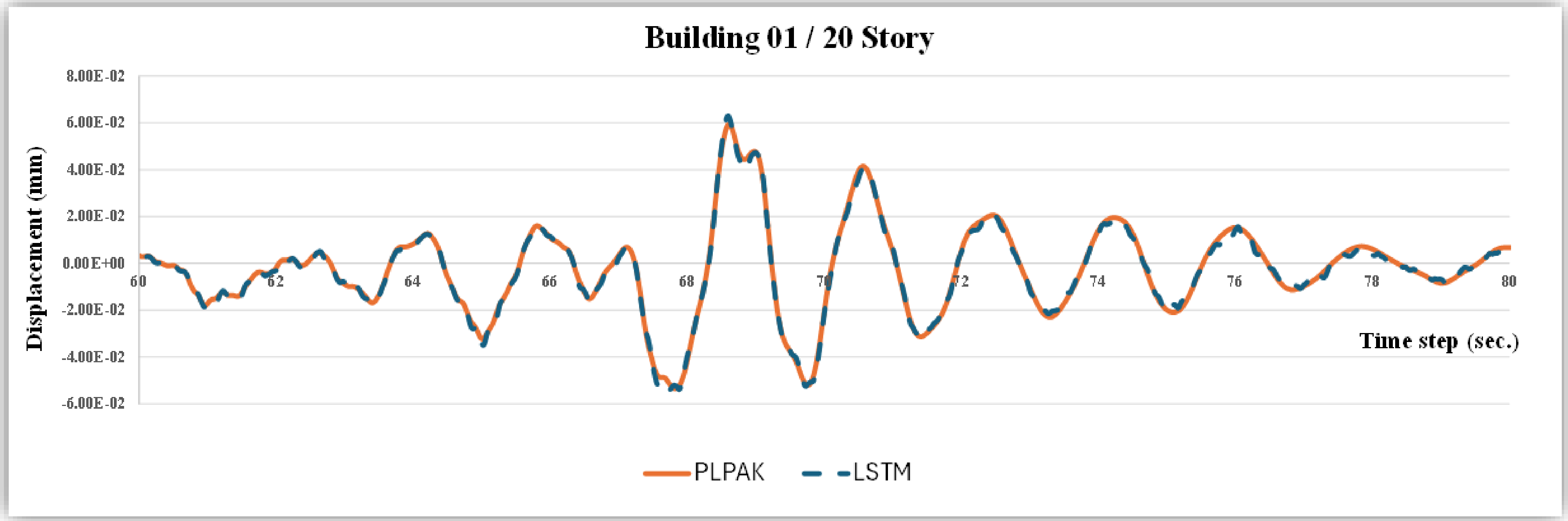

Fig. 22 **Displacement for 1ST building 20-Story**

Results

❑ The first tall building consists of 20 – stories

- **Turkey Earthquake-2023**

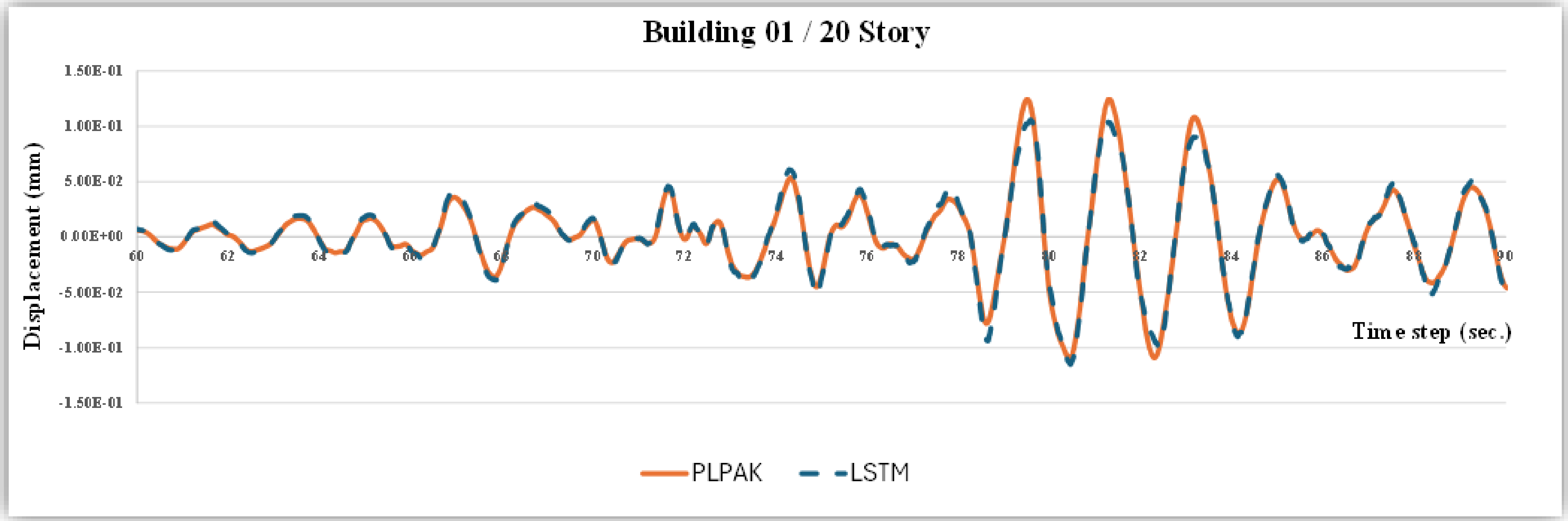

Fig. 22 **Displacement for 1ST building 20-Story**

Results

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❑ The first tall building consists of 40 – stories

- **Aqaba Earthquake-1995**

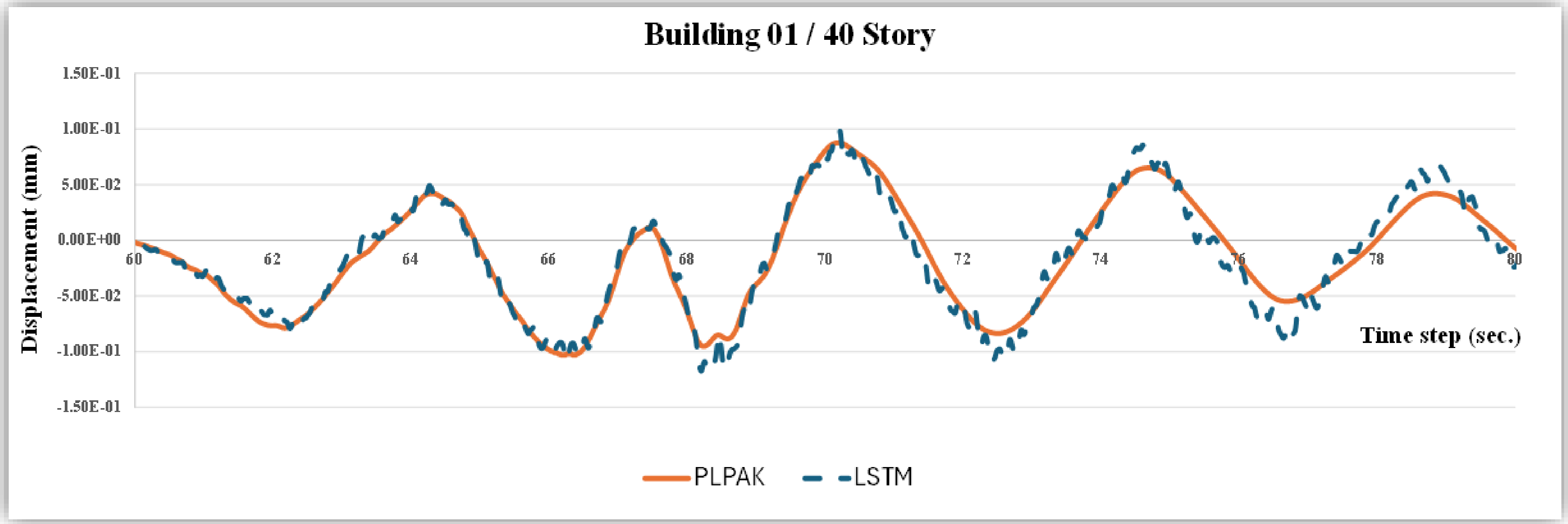

Fig. 23 **Displacement for 1ST building 40-Story**

Results

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❑ The first tall building consists of 40 – stories

- **Turkey Earthquake-2023**

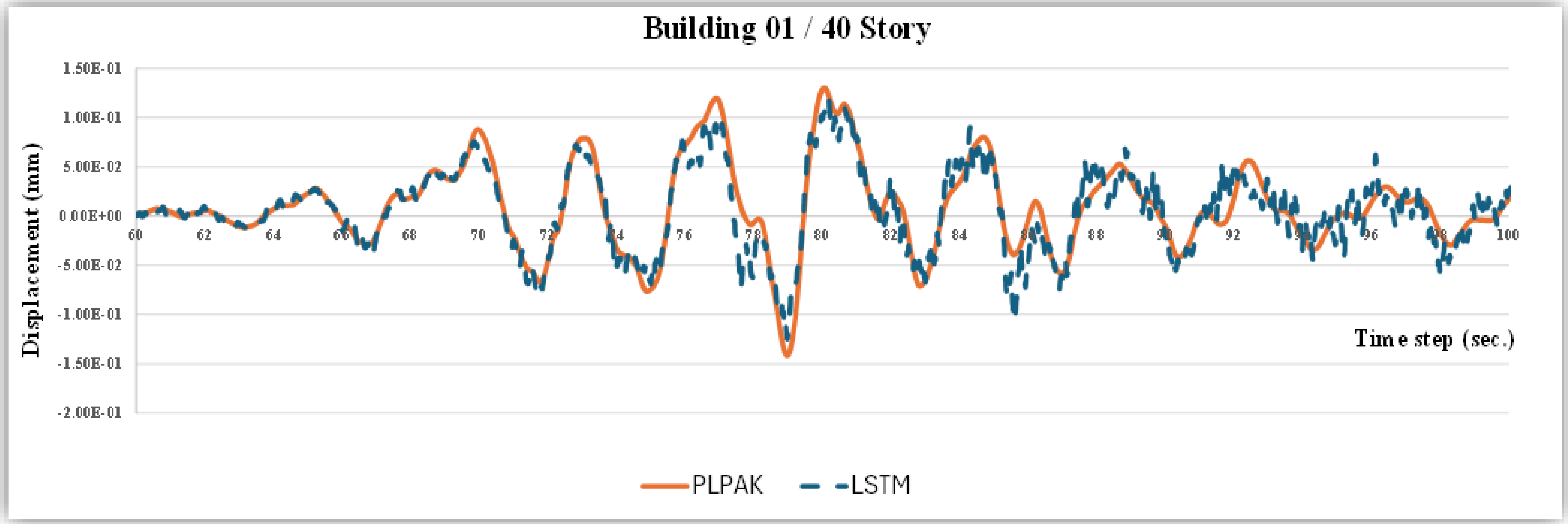

Fig. 23 **Displacement for 1ST building 40-Story**

Results

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❑ The first tall building consists of 60 – stories

- **Aqaba Earthquake-1995**

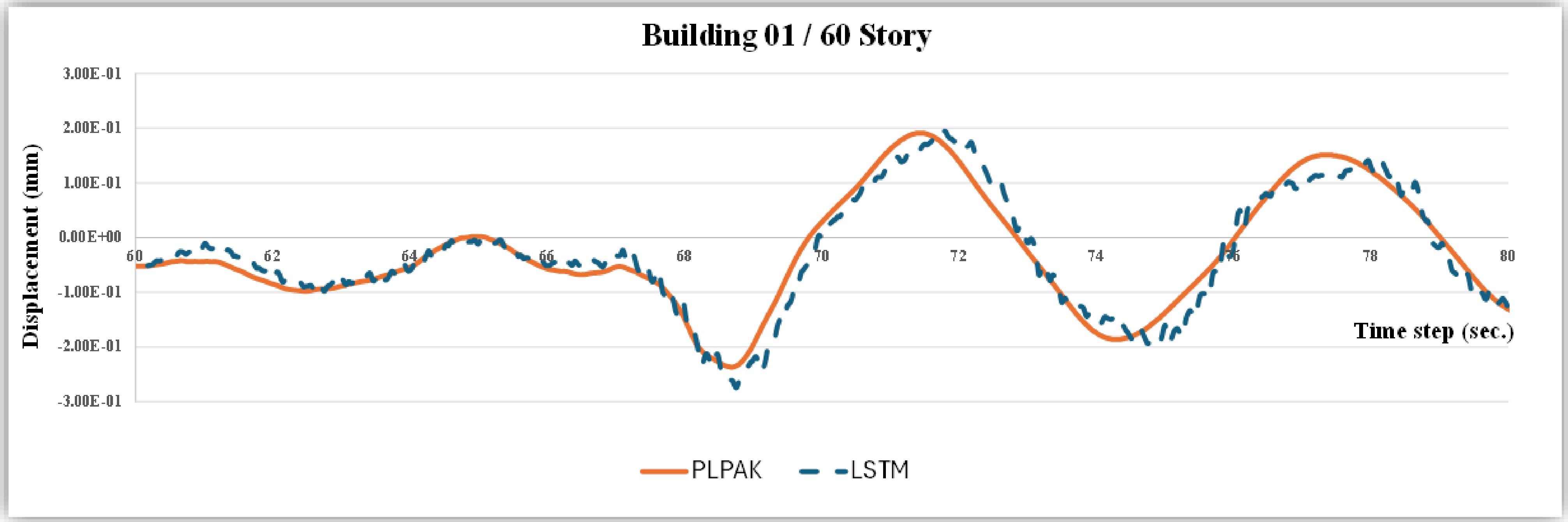

Fig. 24 **Displacement for 1ST building 60-Story**

Results

❑ The first tall building consists of 60 – stories

- **Turkey Earthquake-2023**

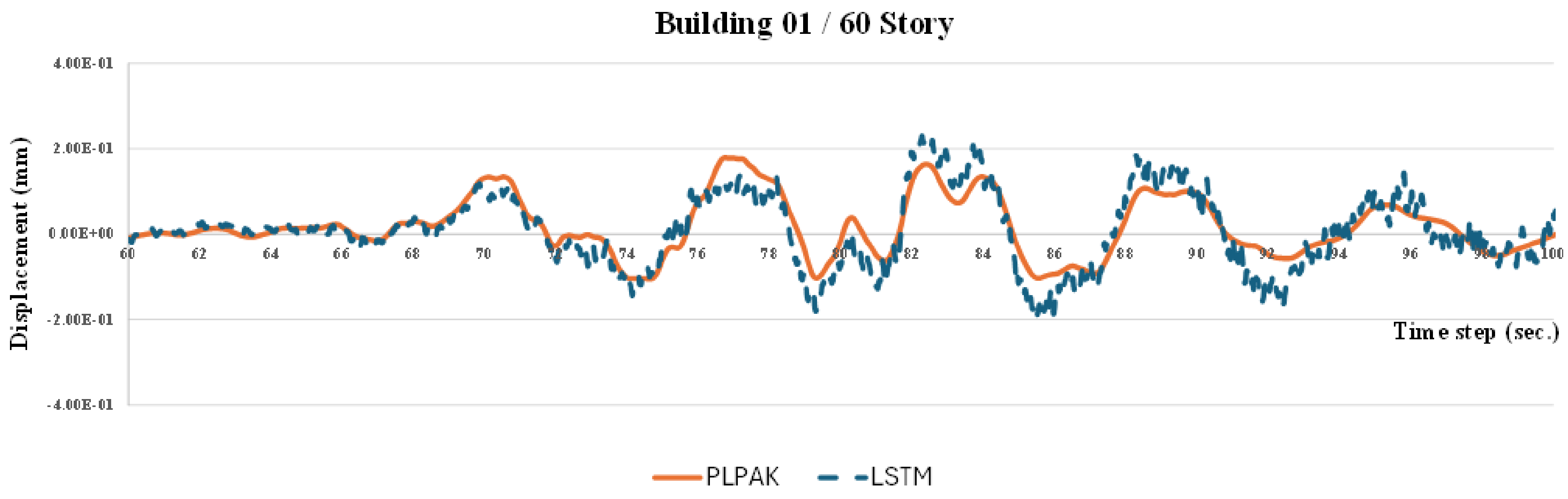

Fig. 24 **Displacement for 1ST building 60-Story**

Results

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❑ The second tall building consists of 10 - stories

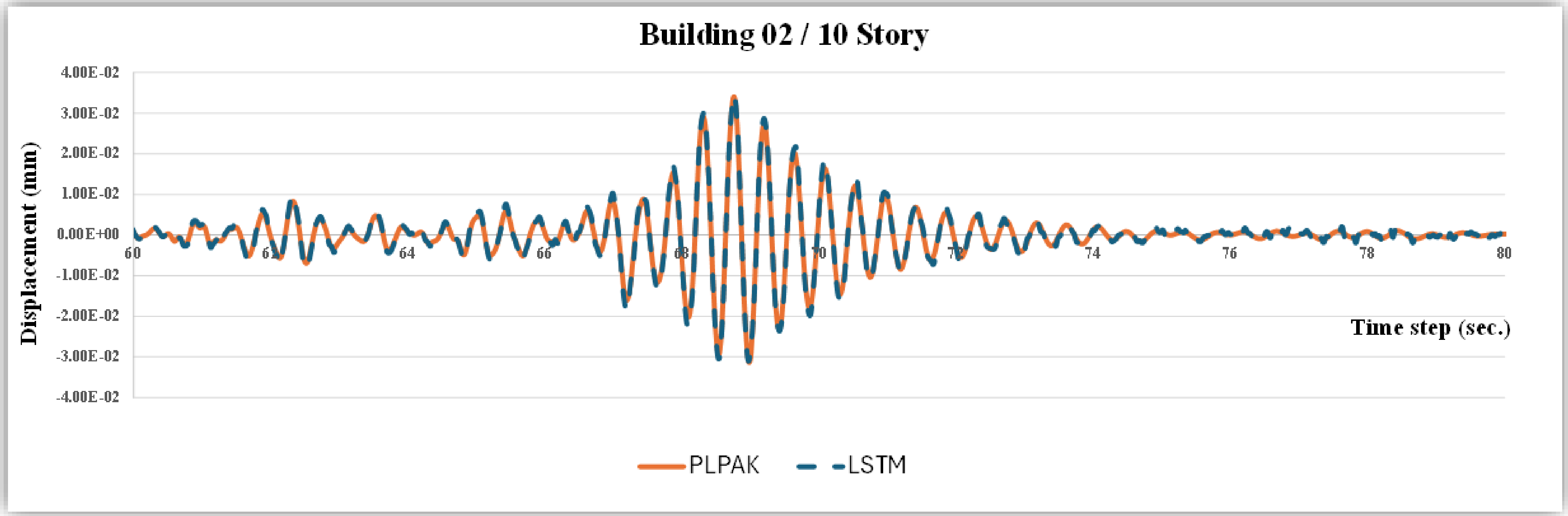

Fig. 25 **Displacement for 2ND building 10-Story**

Results

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❑ The second tall building consists of 20 - stories

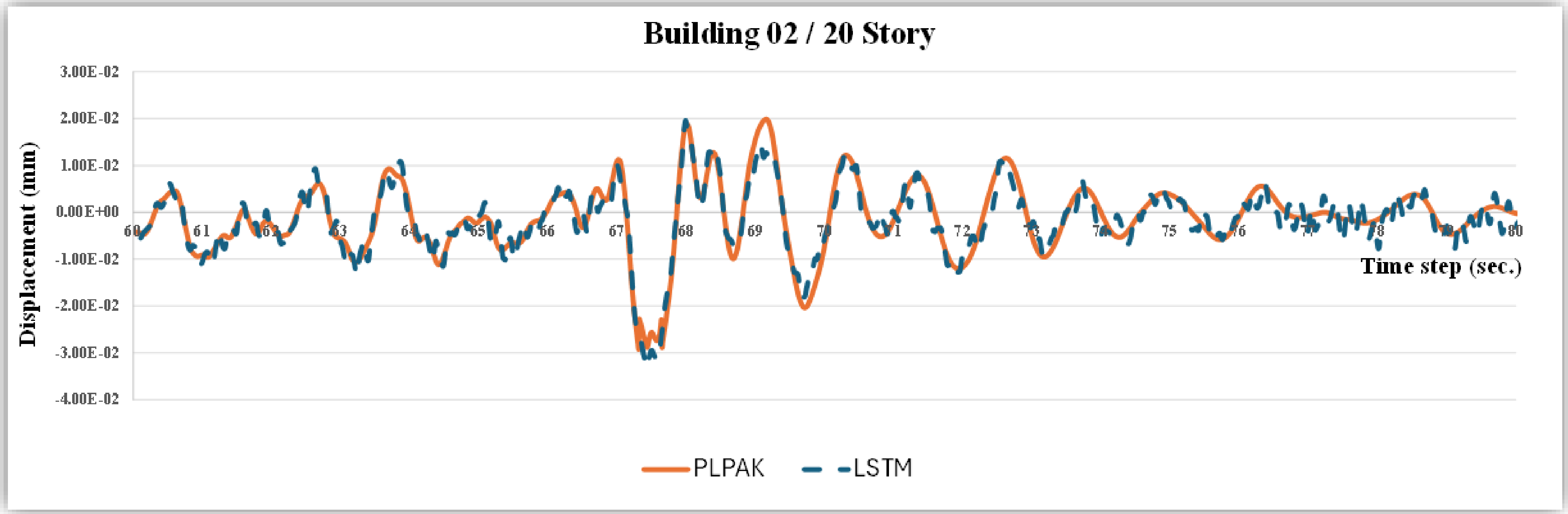

Fig. 26 **Displacement for 2^ND building 20-Story**

Results

❑ The second tall building consists of 40 - stories

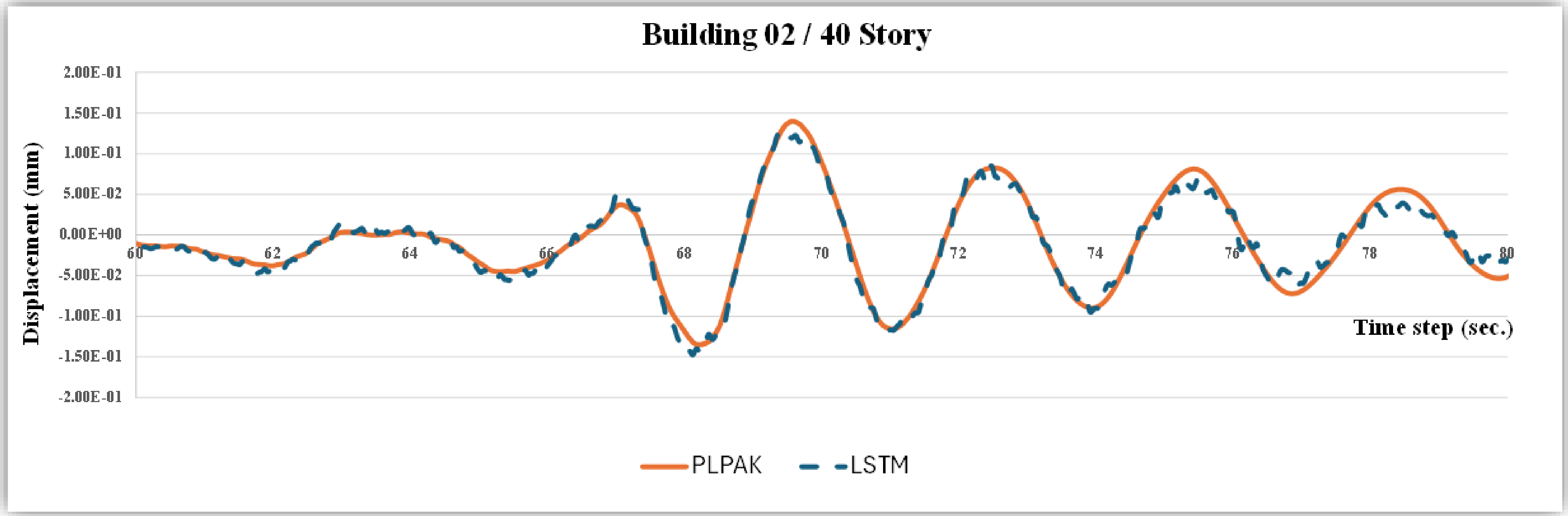

Fig. 27 **Displacement for 2ND building 40-Story**

Results

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❑ The second tall building consists of 60 - stories

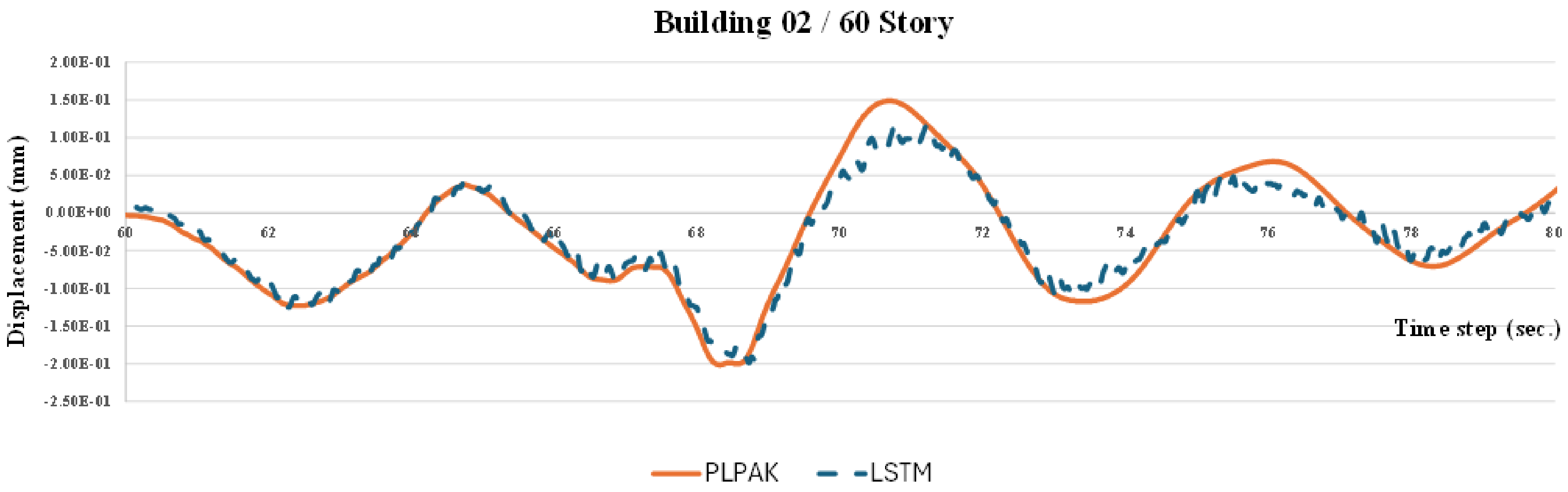

Fig. 28 **Displacement for 2ND building 60-Story**

Results

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❑The third tall building consists of 10 - stories

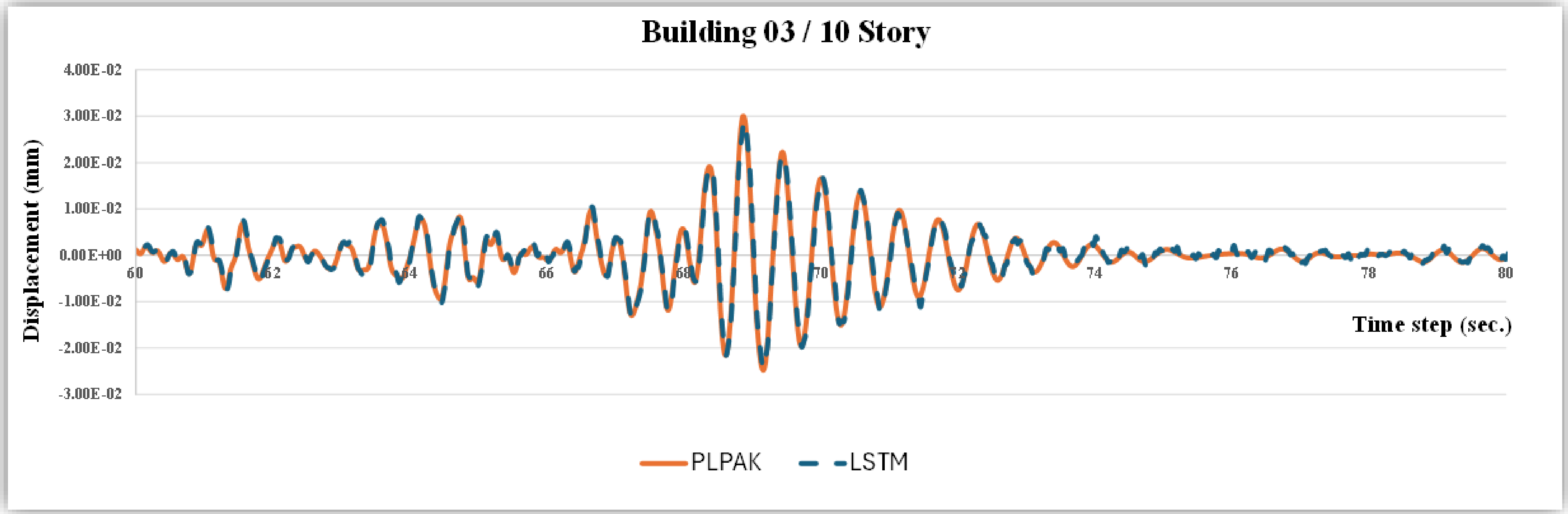

Fig. 29 **Displacement for 3RD building 10-Story**

Results

❑ The third tall building consists of 20 - stories

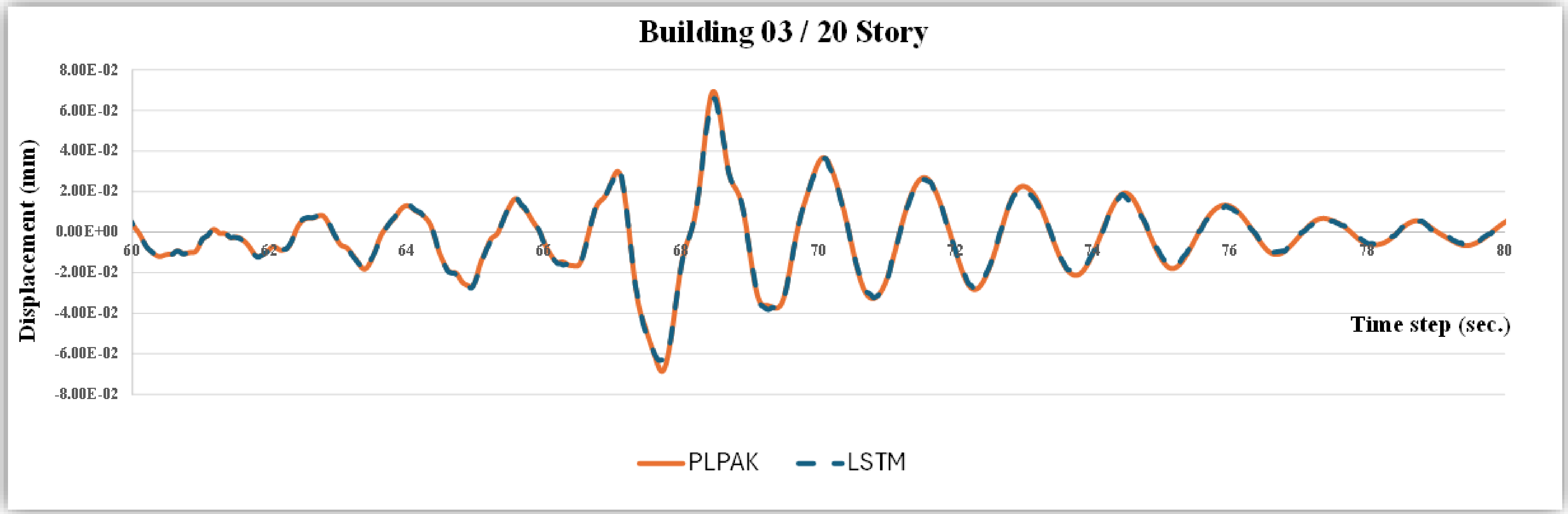

Fig. 30 **Displacement for 3RD building 20-Story**

Results

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❑The third tall building consists of 40 - stories

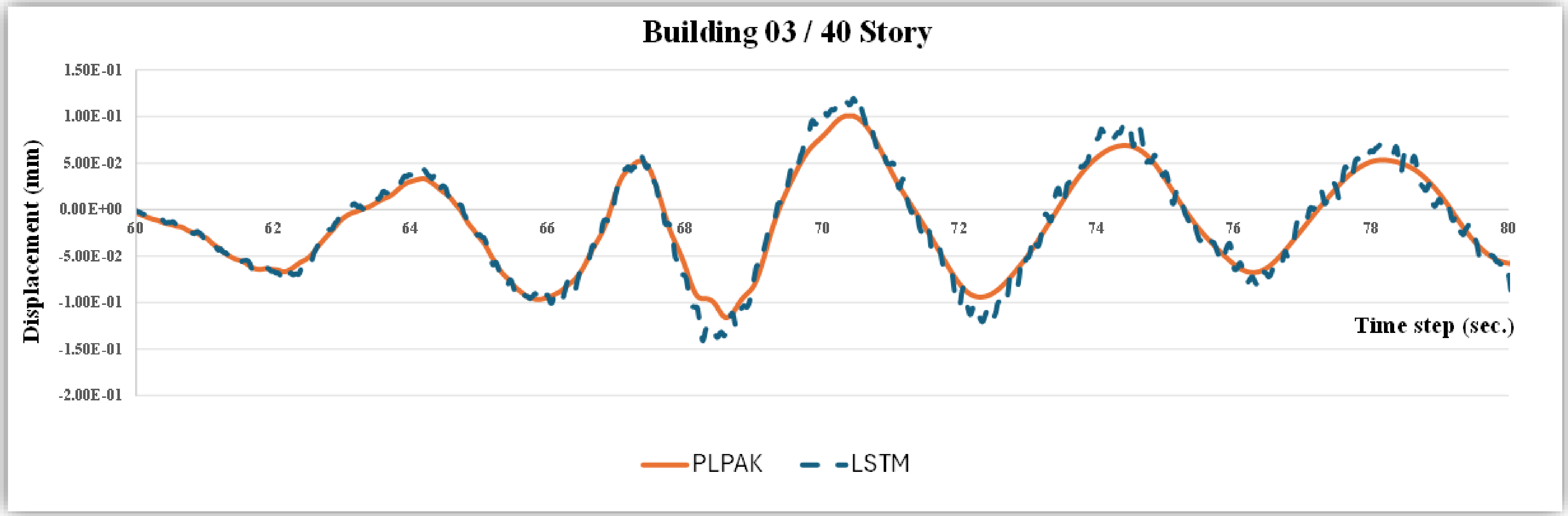

Fig. 31 **Displacement for 3RD building 40-Story**

Conclusions and recommendations work

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- This study successfully demonstrated the potential of **Artificial Neural Networks (ANNs)** combined with **LSTM** to predict the seismic response of tall buildings efficiently.

- The proposed **decoupling approach** (using 3N ANNs) made the model scalable and suitable for complex high-rise structures.

- Validation results showed a **strong agreement** with traditional methods (ETABS and PLPAK), confirming the reliability of the model.

- By reducing computation time and maintaining accuracy, **This approach opens the door to smarter, faster, and safer structural engineering**

Thank You

Presented By / Amany Sayed Ali