MODELLAZIONE NUMERICA DI FACCIATE IN ACCIAIO LEGGERO PER VALUTAZIONI DELLE PRESTAZIONI SISMICHE IN PIANO

NUMERICAL MODELLING OF LIGHTWEIGHT STEEL DRYWALL FACADES FOR IN-PLANE SEISMIC PERFORMANCE EVALUATIONS

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ABSTRACT

A lightweight steel drywall facade (LWS) is one of the most widely used architectural non-structural components of a building. To account for their effect on the structural performance of buildings, simplified numerical models are proposed to simulate their in-plane response. The model can be easily integrated with building models and, when linked to information about their fragility, allows better estimation of damages in them. Models are calibrated experimentally using quasi-static cyclic test results obtained from recent research at the University of Naples "Federico II". Using OpenSees software, models are developed by utilizing a discretized spring to simulate the lumped behavior of the walls for each of the eight different configurations of the tested façades. A comparison of the experimental and numerical results based on the hysteretic response curves and the cumulative energy dissipated demonstrates the accuracy of the model.

SOMMARIO

Una facciata realizzata con un'ossatura in profili sottili in acciaio rivestiti da pannelli rappresenta un componente architettonico non strutturale sempre più diffuso negli edifici. Questo manoscritto presenta uno studio sull'effetto della presenza di questa tipologia di componenti sulle prestazioni sismiche degli edifici. In particolare, vengono proposti modelli numerici semplificati sviluppati con il software OpenSees e in grado di simulare la risposta sismica di sistemi di facciata quando sollecitati nel loro piano. Tali modelli, facilmente integrabili nei modelli strutturali correntemente utilizzati per analizzare la risposta sismica degli edifici, possono consentire anche valutazioni circa la stima dei danni attesi. I modelli semplificati sono calibrati sperimentalmente utilizzando risultati di prove cicliche quasi-statiche su facciate in scala reale effettuate nell'ambito di una recente ricerca condotta presso l'Università di Napoli "Federico II". In particolare, i modelli sono stati sviluppati per ciascuna delle otto diverse configurazioni delle facciate oggetto della sperimentazione. Un confronto tra i risultati sperimentali e numerici in termini di curve di risposta isteretica e di energia dissipata cumulata dimostra l'accuratezza dei modelli.

1 INTRODUCTION

Light Gauge Steel (LGS) framing is an innovative building technology that has been rapidly adopted as a construction method around the world due to its reliable properties like faster installation, resistance to moisture and pests, considerably higher recyclable content, and being an environmentally friendly material. LGS has truly been a game-changer in the construction industry with its evident economic, environmental, and structural advantages that makes it an ideal choice for many construction projects especially residential construction and construction of office buildings.

The seismic behavior of building components, especially the structural members like beams and columns is a well-researched topic as compared to a non-structural components like partition walls and façades. Due to a lack of research and regulations, these non-structural components may be vulnerable during an earthquake event. Damage to these non-structural components causes economic loss and affects the functionality of a building [1] and collapsing partitions or facades can injure people inhabiting the building. Therefore, different research projects [2] are going on to better understand the seismic behavior of these partition walls and façades.

Wang et al. [3] studied the seismic performance of cold-formed steel (CFS) partition walls and facades. The results were based on the shake table test of a five-story building. The study associated the drift demands in the building with the physical damage states of the partition walls. The effects of constructive parameters like stud spacing, sheathing panel type, joint finishing type, and connection types used for connecting the partition walls with the surrounding elements were studied to find their effect on partition lateral response [4]. The test was performed using in-plane quasi-static reversed cyclic loading.

Shakeel et al. [5] developed numerical models of LWS drywall partition walls to simulate their in-plane response to a quasi-static applied loading. The developed numerical models are made using the software OpenSees and possess the ability to be easily integrated with building models and give better damage assessment in the LWS drywall partitions.

The terms façade wall and exterior wall are used interchangeably here. Façade walls vary from curtain walls and cladding in that they are joined to the building face using metal connectors, are not infilled in the building structure, and are non-load-bearing systems. Curtain walls and cladding are held up by the building face to which they are connected. Façade or exterior walls, on the other hand, are often infilled or partially infilled in the building structure. They are not load-bearing, however, and are always supported by the bottom structural element: a beam or floor slab.

Façade walls (Fig. 1) composed of LWS frames are very similar to LWS internal partition walls, with the exception that the panels used in façades on the outer face are normally cement-based panels, which give greater outdoor performance owing to being waterproof and impact resistant. Internal partition walls, on the other hand, are generally composed of gypsum-based panels, which are not suitable for outdoor usage due to their low water resistance. Façades are typically built thicker to improve insulating characteristics. The increased thickness is accomplished by building facades with twin steel frames rather than one. For improved insulation performance, a cavity separates the two frames of the façade walls.

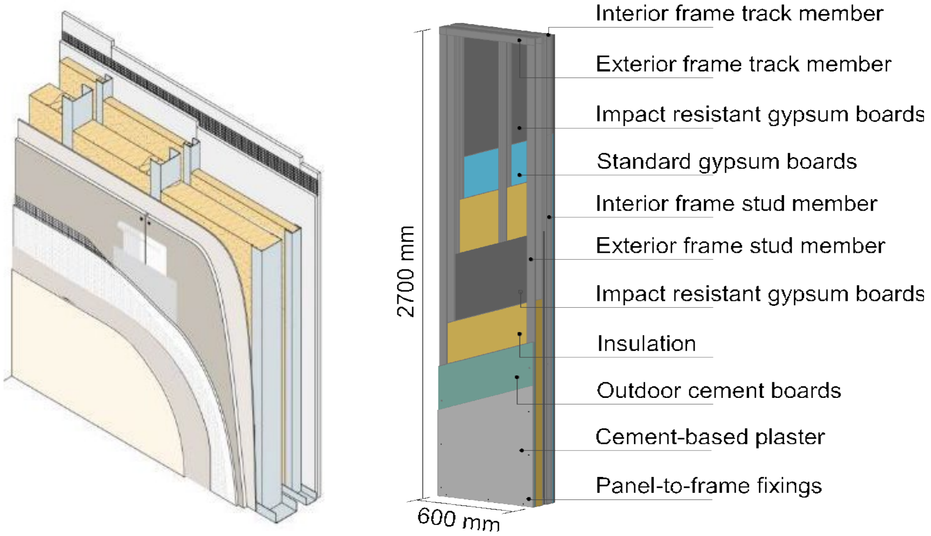

Fig. 1. LGS Facade

The present study mostly focuses on analyzing the seismic behavior of individual LWS façades using the previous test data and developing numerical models. These numerical models will serve as the starting of future studies to investigate the effect of building non-structural components on its structural response. The models are simplified enough to be used in a complete building model and yet accurate enough to simulate the response LWS façades. Façade models are developed in a way so that integrating them with the complete building model would not require further addition of element nodes to the building model.

REFERENCE EXPERIMENTAL DATA

Numerical models are calibrated using the test data. Experimentation was carried out at the University of Naples Federico II, Italy. The tested facades were made of LGS frames sheathed with gypsum-based boards. In-plane quasi-static reversed loading was applied to test the façade models. 8 configurations (Tab. 1) of outdoor facades were tested for parameters such as type of connection of façade to surrounding structural elements, type of surrounding element on the sides, and type of panel.

NUMERICAL MODEL

A simplified model (Fig. 2) incorporating a zero-length spring element is generated in OpenSees [6]. The zero-length element is made of Pinching4 material [7]. Pinching4 is a uniaxial material that can depict pinched load-deformation response and can degrade when subjected to cyclic loading.
Individual facade models are created for each of the eight tests based on their test results. This is accomplished using the pinching 4 material's four-point backbone rule which encapsulates the envelope of the experimental hysteretic response curve as well as the strength deterioration detected after the façade has reached its maximal strength.

The selection criteria for the four points of the backbone curves are:

- **Point 1:** The force is derived using 20% of the peak force noted during the test (Fp), and the displacement is the equivalent displacement at that point.
- **Point 2:** The force is derived using 80% of the peak force, and the displacement is set using an energy balancing rule so that the area below the experimental hysteretic envelope curve up to the peak point equals the area below the numerical backbone curve up to the peak point.
- **Point 3:** The force is assigned as the peak force measured during the test (Fp), and the displacement is the corresponding displacement at that location.
- **Point 4:** The force is derived using an energy balance to have an identical area below the experimental hysteretic envelope curve and the numerical backbone curve's third and fourth points. The displacement varies from 2% - 4% of the inter-story drift ratio (IDR).

The path of the hysteretic response is controlled by a set of parameters, which are as follows:

- uForceP: The ratio between the strength created upon unloading and the maximum strength of the positive backbone curve
- rDispP and rForceP: mark the strength and displacement at which reloading occurs.
- Cyclic parameters were calibrated by hit and trial method so that the numerical model can dissipate a similar about of energy as the reference experiment test along and it captures the overall shape of the experimental force-displacement hysteretic response.
- The same cyclic loading protocol (Fig. 3) as used in the tests has been used to analyze the model. This loading protocol has been defined by FEMA 461 [8] as “Interim testing protocols for determining the seismic performance characteristic of structural and non-structural components”. FEMA 461 provides a loading history that consists of repeated cycles of stepwise increasing deformation amplitudes.

Table 1. Reference Experimental program.

Label	Protrusion / offset (mm)	Material	Studs	Tracks / Brackets	External frame Interior face	External frame Exterior face	Internal frame Exterior face	Additional Finishing
W-01	No	Steel box profiles	C 75x50x0.6	U 75x40x0.6	1 x Diamant	1 x Aquapanel	2 x Diamant	No
W-04	No	Steel box profiles	C 75x50x0.6	U 75x40x0.6	1 x Diamant	1 x Aquapanel		No
W-05	No	Steel box profiles					2 x Diamant	No
W-06	No	Steel box profiles	C 75x50x0.6	U 75x40x0.6	1 x GKB	1 x Aquapanel		No
W-07	No	Steel box profiles	Slotted KAW C 150x45x1.0	1.0 mm thick. slotted L-brackets	1 x GKB	1 x Aquapanel		No
W-10	No	Steel box profiles					2 x GKB	No
W-18	No	Steel box profiles	Slotted KAW C 150x45x1.0	1.0 mm. slotted L-brackets	1 x GKB	1 x Aquapanel		No
W-20	No	Steel box profiles	C 75x50x0.6	U 75x40x0.6	1 x GKB	1 x Aquapanel		No

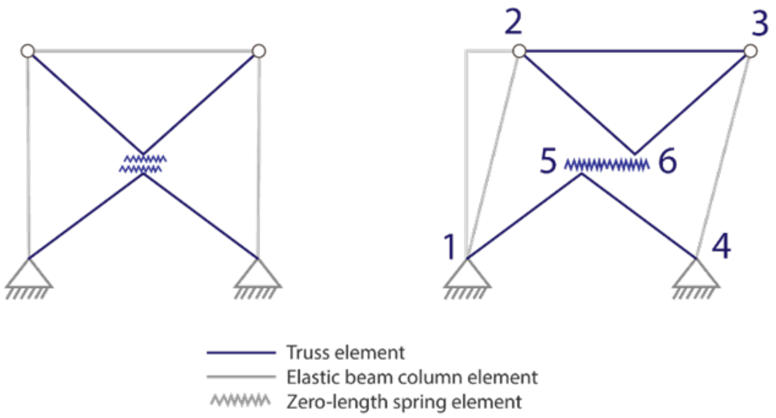

Fig. 2. Schematic of OpenSees model

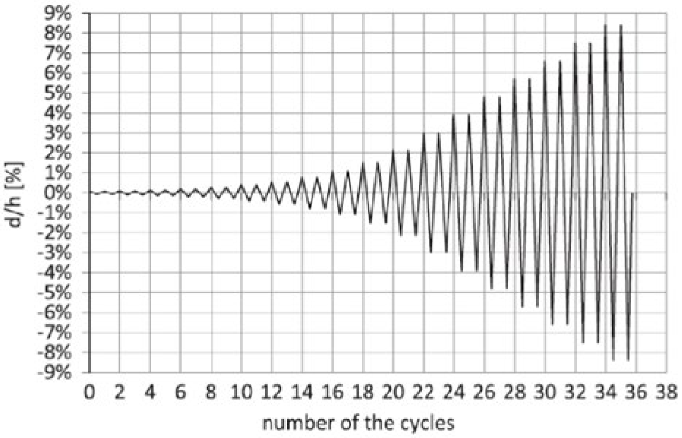

Fig. 3. Cyclic Loading protocol [8]

RESULTS

Fig. 4 shows the comparison of force-displacement (F-D) hysteretic curves and energy dissipation between numerical and experimental results for Test 1 and 6. It can be seen that the numerical model effectively captures the F-D response of the tested façade configurations, both in terms of the peak points and the overall shape of the response. The energy dissipation of the experimental and numerical results has the same general trend.

But to check the accuracy of the facade models, a comparison between the experimental and numerical results was made based on the dissipated energy using the following equations:

$$CEe,j = \sum Ee,i\ j\ i{=}1\ ,\ [i,j \leq n] \qquad (1)$$

$$CEn,j = \sum En,i\ j\ i{=}1\ ,\ [i,j \leq n] \qquad (2)$$

$$\Delta E,i{=}\ En,i{-}Ee,i\ Ee,i \times 100,\ [i \leq n] \qquad (3)$$

$$\Delta CE,j{=}\ CEn,j{-}CEe,j\ CEe,j \times 100,\ [j \leq n] \qquad (4)$$

where: $CEe,j,$ and CEn,j represent the cumulative energy dissipated until the jth cycle of the loading protocol obtained from experimental and numerical results, respectively; Ee,i and En,i represent the energy dissipated in an ith cycle of experimental and numerical results, respectively; $\Delta E,i$ is the percentage difference of the energy dissipation between numerical and experimental results for an ith cycle of the loading protocol; $\Delta CE,j$ is the percentage difference of the cumulative energy until the jth cycle of loading protocol between numerical and experimental results; n is the last cycle of the loading protocol.

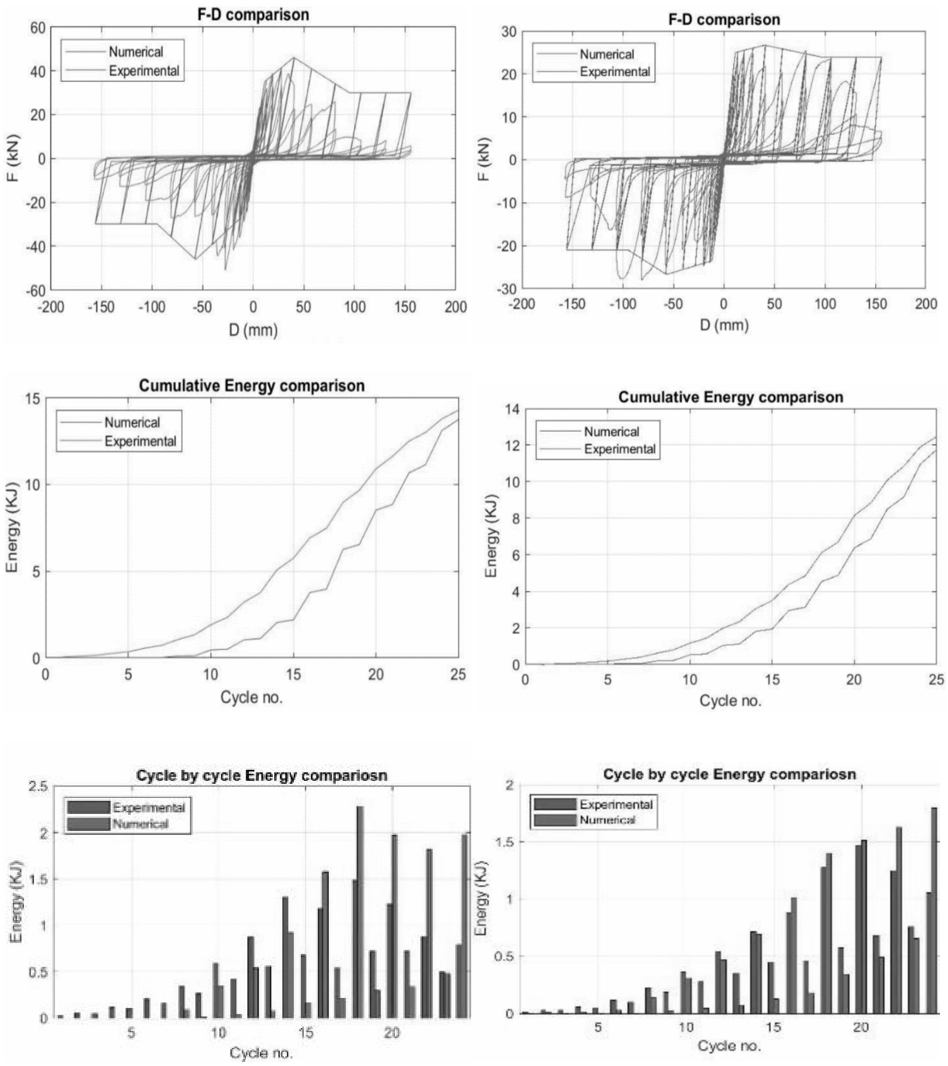

Fig. 4. Comparison of experimental and numerical results (left: test 1, right: test 6)

Numerical models underestimate the cumulative energy for all tests. In particular, absolute values of $\Delta CE{,}j$ for all numerical models for the respective tests were within the range of 5 to 10% for the last cycle of a loading protocol. The absolute average value of $\Delta E{,}i$ for all tests at bigger amplitude cycles of the loading protocol were also within 15%. It can also be seen from these figures that the energy dissipated in Test 1 is much greater than in Test 6. This may be due to the type of connection the facade has to its surroundings. Test 6 has a sliding connection which may explain the lower energy dissipation while Test 1 has a fixed connection.

CONCLUSION

For LWS drywall façades, simplified models based on a single spring element coupled with the global hysteretic response of the wall are presented. Models for LWS facades produced with CFS framing sheathed with gypsum-based panels are presented in particular. The modeled façades differ in the following ways: the connection of the wall to the surrounding structural elements (fixed or sliding); the spacing between the wall's steel studs; the type of panel, the type of finishes; and the type of surrounding elements on the sides: structural elements or façades. The model is calibrated using experimental data on the in-plane behavior of the façades collected from previous quasi-static cycle testing on them. Each façade's model is capable of simulating its hysteretic response

The capacity of the model to reproduce the experimental response is assessed using visual comparisons of the experimental and numerical hysteretic responses, as well as quantitative comparisons in terms of energy dissipation. In fact, the difference in cumulative energy dissipation at the last cycle between numerical models of individual façade wall configuration and actual data is in the range of 5% to 10%. In the future, the proposed models will be used to undertake a case study to assess the impacts of architectural non-structural components on building seismic performance. Because of the simplicity of the models shown here, they may also be used as a reference for engineers who want to include the contribution of these elements into the structural response of a building model.

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KEYWORDS

simplified spring model, lightweight steel structures, partition walls, OpenSees, and In-plane seismic response.