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Investigation of concrete structures with wasp nest dampers against explosive loads

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Abstract

This research investigates the explosive behavior of reinforced concrete frames retrofitted with wasp nest dampers. One effective solution for minimizing structural damage is the implementation of dampers, which function by absorbing energy and thereby reducing damage resulting from applied loads. One of the relatively recent damper types used is the wasp nest damper. Due to the limited knowledge regarding the explosive behavior of these dampers within concrete frames, this study aims to comprehensively address their behavior under explosive conditions. This investigation examines various parameters, including wall thickness, the arrangement of dampers in rows and columns, and their influence on the explosive behavior of frames retrofitted with these dampers. To achieve this objective, six models were analyzed in this research, and their results were validated using Abaqus software. In all models, an explosive load equivalent to a 50-kilogram TNT explosion at a distance of 3 meters from the structure was applied. The analysis involved the measurement of displacements and stresses and the generation of contour plots depicting tensile and compressive damage within the structure. The variables under scrutiny in this study encompassed the thickness of the wasp nest damper walls and the number of rows and columns. The obtained results demonstrate that using wasp nest dampers can significantly mitigate damage from explosive loads on the structure. Furthermore, it was observed that increasing the thickness, columns, and rows of wasp nest dampers can enhance their performance and effectiveness.

Keywords: Wasp Nest Damper; Reinforced Concrete Frame; Abaqus; FEA; Explosive Loads

1. Introduction

In recent decades, the use of dampers in the seismic engineering design of new-generation structures has become widespread. These dampers are used to mitigate the damages caused by various events such as explosions and earthquakes by absorbing the energy generated by these loads, thus minimizing the structural damage [1]. Different types of dampers have been employed in structures, including viscous dampers, metallic yielding dampers, and friction dampers. Among these, metallic-yielding dampers are more common due to their inelastic response to the environment and cost-effective construction. Among the different types of metallic yielding dampers, steel plate yielding dampers have been extensively researched, reinforced with recycled concrete Frame. The construction industry's ecological impact underscores the urgency for innovative waste reduction solutions. Concrete and demolition waste emerge as a significant proportion of the overall waste, considering concrete's widespread use in construction. recycling, yields multiple advantages, including diminished resource demand and lowered energy expenses. This recycling practice not only attends to environmental apprehensions but also holds economic benefits The construction industry's ecological impact underscores the urgency for innovative waste reduction solutions. Among these principles, recycling, particularly concerning concrete, yields multiple advantages, including diminished resource demand and lowered energy expenses. This recycling practice not only attends to environmental apprehensions but also holds economic benefits [2]. Kiani and Hashemi in 2021, The study introduced a new hybrid damper called the Vertical Links System with Double-Stage Yielding (VLDY). The system consists of two replaceable vertical shear links connected in series within a moment-resisting frame. The minor link can be adjusted to dissipate energy during moderate earthquakes,

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while the major link maintains structural integrity. A validated modeling protocol in ABAQUS/standard showed that the VLDY device provides stable energy dissipation capacity across inter-story drift levels [3]. Additionally, dampers with added stiffness and strength (ADAS) and triangular dampers (TADAS) have been designed to absorb seismic energy by yielding flexure outside the plane. Their triangular shape-cut plates ensure a constant length, maximizing the energy absorption per unit volume of steel. Furthermore, grooved and helical dampers have been designed for in-plane flexural yielding. Laboratory findings have shown that grooved and helical dampers exhibit stable energy absorption characteristics. However, one common limitation in flexural yielding dampers is their relatively low initial stiffness.

In general, multi-plate or strip dampers are required to achieve the necessary stiffness against explosive and seismic loads. For example, the Yielding Shear Plate Damper (YSPD) is designed based on shear-yielding principles, where square steel plates are cut and welded into a hollow steel section (HSS). Shear yielding of the steel plate provides high initial stiffness. Nevertheless, the construction and design of YSPD are complicated due to the precision required for cutting and welding the plates into the complex section. Moreover, the behavior of steel plates and HSS is highly nonlinear, complicating the design of YSPD. Recently, a special metallic damper called the Welded-Wide Flange Frame Damper (WWFF) has been developed. WWFF utilizes readily available wide-flange sections to absorb seismic energy through shear yielding of the web while the flanges remain in tension. WWFF offers extensive advantages such as economical and cost-effective construction, simple design, and efficient energy absorption capacity. However, it has been observed that thin-walled sections with high slenderness tend to buckle out-of-plane under relatively low drifts, resulting in local and compressive failures [1]. These days, the improvement of the stability of structures under various loads is one of the most significant issues. In order to reinforce the structures, researchers are working on enhancing the material properties [4]. For example, Ferdosi and Porbashiri used the asymptotic homogenization method to study the mechanical properties of carbon nanotubes. They utilized MATLAB to model and simulate nanotubes, considering chiralities like armchair and zigzag. Young's and shear modulus are estimated, and the study explores the impact of diameter and orientation [5]. Moreover, researchers are studying the stability of structures to find new approaches to make them stronger against collapsing [6-7].

Research shows that careful concentration adjustments can improve damage reduction in anti-icing materials. Calcium magnesium acetate is the most effective anti-icing agent, effectively mitigating issues like metal corrosion and concrete deterioration. However, increasing potassium acetate concentration may worsen environmental impacts, leading to moisture damage and asphalt fatigue. Therefore, responsible and optimal use of anti-icing materials can enhance environmental properties and boost economic efficiency [8].

Given the mentioned issues in this study, a novel steel plate damper called the Wasp Nest Damper (WND) is proposed, based on previous research on WWFF. The difference is that WND incorporates a honeycomb-like cavity in its core [1]. This damper is attached to the upper portion of a concrete structure using a restraint system, which can absorb the energy generated by explosive loads and mitigate damage to the structure. Based on the investigations conducted by Yang and colleagues, it is recommended to be used in the structure presented in this research, and its explosive behavior and the improvements it brings to the structure will be examined. A schematic of the damper used in the proposed concrete structure in this study is presented in Figure 1.

Figure 1 The Wasp Nest Damper Used in the Proposed Concrete Structure in this Study

In contemporary structural design, the primary concern revolves around ensuring the stability of structures when subjected to various loads. In response to this challenge, some researchers are diligently exploring diverse approaches and techniques aimed at enhancing the dependability of structures under different loads. As an illustration, Mohammad Ali and colleagues [9] have undertaken a study to investigate the buckling behavior of elliptical CDFST (Concrete-Filled

Double-Skin Tube) columns by incorporating transverse reinforcements within the outer tube. In this research, they conducted simulations of elliptical columns exposed to compressive loading using Abaqus Software. The outcomes of this investigation reveal a notable improvement in the load-bearing capacity, particularly in columns that employ transverse reinforcements, thereby bolstering the stability of these columns when subjected to loads. Kiani et al. 2015, investigated the local seismic stability of flanged cruciform sections (FCSs). They studied local buckling, flexural ductility, and P-MP interaction relationships of flanged cruciform sections (FCSs). A validated material and geometric nonlinear finite element model in ABAQUS were used for a comprehensive parametric study. A new web seismically compact limiting ratio was proposed for FCSs, considering web slenderness and axial load [10].

Jung and Aref, 2003, conducted a study on the hybridization of honeycomb nest bee absorbers with viscoelastic solid materials to develop a composite polymeric damping system [11]. Motamedi and Nateghi, in 2004, investigated the use of accordion-shaped thin-walled tubes as metallic dampers. Subsequently, finite element modeling and nonlinear dynamic analysis were employed to examine this damper's behavior, including stiffness, stress distribution, hysteresis loops, degradation effects such as reduced resistance and stiffness, and energy absorption capacity under cyclic axial loads. The findings indicated that the proposed damper exhibited stable behavior under compression and tension, providing efficient and effective energy dissipation [12].

In 2008, Chan and Albermani conducted experimental research on grooved steel dampers for energy dissipation [13]. Oh and colleagues, in 2009, investigated the seismic behavior of steel structures equipped with grooved dampers. The results demonstrated that the proposed connections exhibited excellent post-yield behavior. Furthermore, energy absorption and plastic deformation were concentrated mainly in the grooved dampers, allowing for the avoidance of yielding behavior in beams and columns due to the design approach [14].

In 2012, Heidari and his team introduced a novel post-yield metal damper with corrugated circular plates. Finite element analysis and nonlinear dynamic analysis were employed to examine various aspects, including damping, stress distribution, hysteresis loops, degradation effects such as reduced resistance and stiffness, and energy absorption capacity. The findings of this research indicated that this damper exhibited suitable and stable behavior under monotonic loading [15]. In 2015, Zheng and colleagues investigated shape-variable steel dampers with non-hexagonal vertical grooves through analytical and experimental studies [16]. Teruna and his team, in the same year, studied steel post-yield dampers for energy absorption. They also developed numerical models for post-yield steel plate dampers with rhombic-shaped holes to enhance energy absorption [17-18]. In 2015, Naeem and colleagues conducted a study on honeycomb nest bee steel dampers for seismic retrofitting of structures [19].

In 2016, He and his colleagues investigated the energy dissipation performance of hybrid steel sheet dampers with low yield points based on optimization principles [20]. In 2017, Lee and colleagues conducted a study on seismic retrofitting using steel honeycomb nest bee absorbers. For this purpose, computational relationships for initial stiffness and yield resistance of the absorber were extracted based on the cell wall bending model and compared with data obtained from finite element analysis [21-22]. In the same year, Lee and Kim worked on the development of box-shaped steel honeycomb absorbers for seismic retrofitting. In this research, a steel honeycomb absorber was developed by assembling four steel honeycomb sheet elements in a square steel section, capable of providing substantial damping compared to conventional steel honeycomb absorbers made from a single sheet [22]. In 2019, Farrokhnia and Movahedifar investigated the behavior of structures equipped with honeycomb nest bee absorbers against explosions and earthquakes [23].

In 2020, Yang and colleagues [1] conducted experimental and numerical studies on honeycomb nest bee absorbers. In this research, they introduced a novel model of metal absorbers for seismic applications. This absorber was constructed using welded wide-flange sections with honeycomb voids in the core, designed to absorb seismic energy through plastic deformation of the core while the flanges remain in an elastic state. Honeycomb nest bee absorbers can be customized in various forms to meet the demands of different structures. To assess the performance of these absorbers, nine specimens with varying geometric parameters, such as the aspect ratio of the cell wall thickness to its central length and the arrangement of honeycomb cells (number of rows and columns), were fabricated and tested under cyclic quasi-static loading. The effects of different geometric parameters on initial stiffness, yield force, yield drift, force-displacement relationship, buckling, and failure modes were summarized. Finally, a finite element model was developed to simulate the post-yield behavior of these absorbers and its efficiency was validated by comparing it with experimental results. The findings of this research demonstrated that the proposed honeycomb nest bee absorber exhibits stable energy absorption behavior and can be effectively used as a metal absorber for seismic applications [1]. The honeycomb nest bee absorber investigated in this study will be used as the base absorber for the analyzed structure in further research, and the results will be validated based on the outcomes presented for this absorber. The honeycomb nest bee absorber presented in this study is shown in Figure 2.

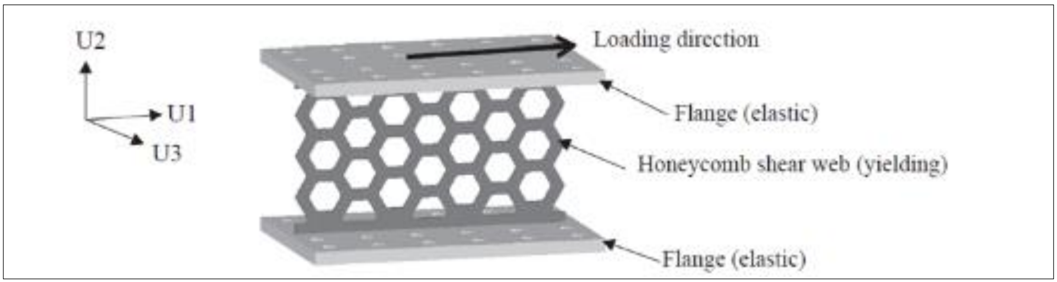


Figure 2 The proposed honeycomb nest bee damper in the study by Yang and colleagues [1]

2. Foundations of research

2.1. Validation Model

This study investigates explosions in frames equipped with honeycomb nest bee dampers in two parts. Due to the lack of articles on explosion behavior concerning honeycomb nest bee dampers, a reference to the article by [1] has been utilized for validation purposes of their seismic behavior. In the second section, the primary models of this research explore the explosion phenomenon on these frames with honeycomb nest bee dampers incorporated into various concrete frame configurations. Parameters such as the thickness of the honeycomb nest bee damper walls, the number of rows and columns, and their impact on the explosion behavior of the frame are examined. Model a0.3r3c4 from the reference paper by [1] has been selected to validate the simulation process. Relevant parameters regarding the honeycomb nest bee damper and its shape are presented in Figure 3.

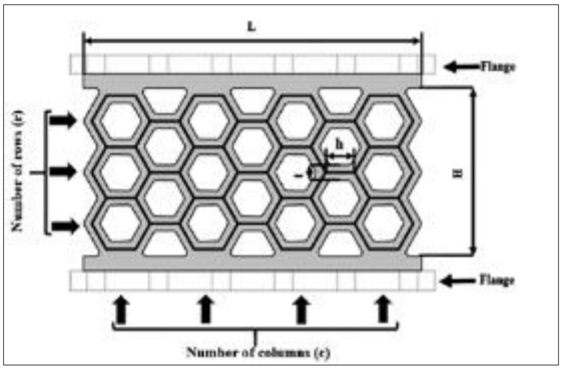


Figure 3 Geometry and Parameters of the Honeycomb Nest Bee Damper [1]

The selected sample, denoted as a0.3r3c4, has a t/h ratio of 0.3 and consists of 3 rows and 4 columns. The reason for this naming convention is due to these parameters. The values of the parameters used in the honeycomb geometry analyzed in this study are presented in Table 1.

Table 1 Geometry Parameters of the Validation Model [1]

Sample	Thickness(mm)	h (mm)	t/h	H (mm)	L(mm)
a0.3r3c4	4.8	37.2	0.3	203.2	418

As shown in Table 1, the sample has a thickness of 4.8 mm, with three rows and four columns. The thickness-to-side ratio of the hexagonal cells of the honeycomb is 0.3, which, given the value of 37.2 mm for 'h', results in 't' being equal to 11.16 mm. Based on these values, the desired sample was drawn in the Abaqus software, and the geometry of the model is presented in Figure 4.

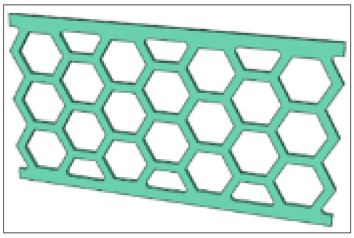


Figure 4 Geometry of the validation model used in this study

Also, the material used in this study for the validation of the honeycomb damper is ASTM-A370-17, and its properties are provided in Table 2, with the stress-strain curve shown in Figure 5.

Table 2 Properties of the steel used for the honeycomb damper in the validation section [1]

Young's Modulus (GPa)	Poisson's Ratio	Yield Stress (GPa)
200	0.3	256

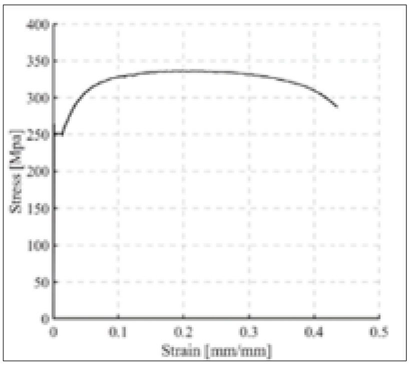


Figure 5 Stress-Strain Curve of the ASTM-A370-17 Material Used in the Validation Section [1]

The lower part of the honeycomb-like brace, as shown in Figure 6, is constrained, and seismic loading is applied to the upper part of the model, following the protocol presented in Figure 7, similar to what is depicted in Figure 8.

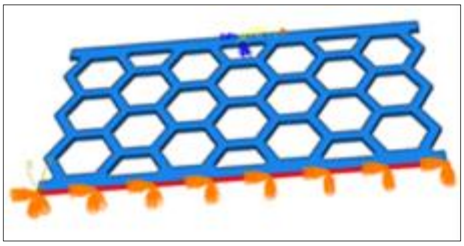


Figure 6 Confinement of the Lower Part

After confining the lower part of the model, seismic loading is applied to the reference point defined in the previous section, following the protocol presented in Figure 7, as shown in Figure 8.

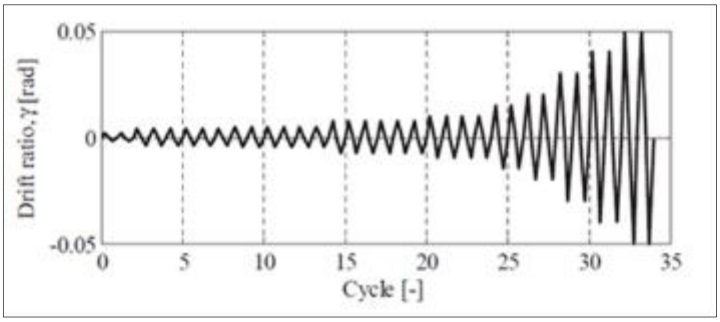


Figure 7 Seismic Loading Protocol in the Validation Model [1]

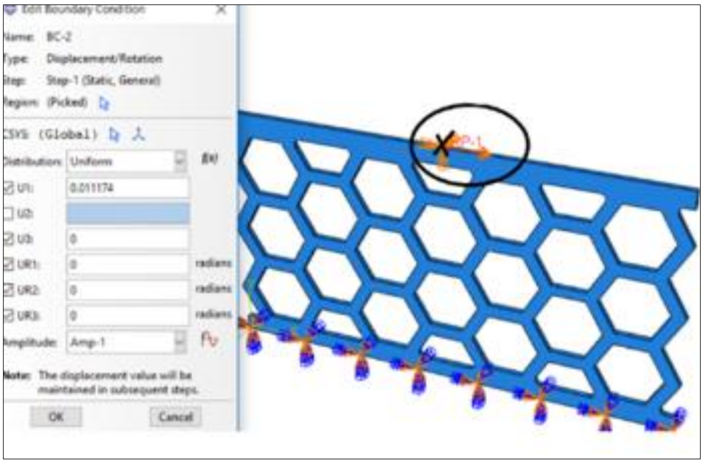


Figure 8 Location of Seismic Loading Application

For meshing the validation model, a 2-millimeter grading is used, and the type of mesh chosen is C3D8R, which is an 8-node three-dimensional element. The meshed model is presented in Figure 9.

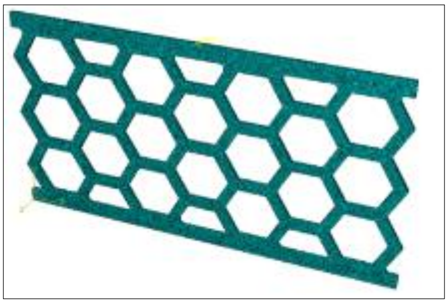


Figure 9 Meshing of the Validation Model

2.2. Description of 6 Models in this Study

In this section, 6 models have been analyzed in the Abaqus software. Model 1 represents the base model, which is a simple concrete structure with a single bay and without honeycomb cores. In Model 2, two honeycomb core stiffeners are attached to the concrete structure. The specifications of the honeycomb cores in Model 2 are the same as those analyzed in the validation section. In Models 3 and 4, the thickness of the honeycomb cores has been increased. In Model 5, the number of columns in the honeycomb cores has increased from 3 to 4, and in Model 6, the number of rows in the honeycomb cores has decreased from 4 to 3, aiming to determine the effect of thickness and changes in rows and columns on the seismic response of the structure. The specifications of the analyzed models in this study are presented in Table 3.

Table 3 Specifications of Analyzed Models in this Study

Sample	L(mm)	H (mm)	t/h	t(mm)	h (mm)	#columns	#rows
Sample1	Without shear walls and honeycomb brace						
Sample2	418	203.2	0.3	11.2	37.2	4	3
Sample3	418	203.2	0.5	17.8	35.7	4	3
Sample4	418	203.2	0.7	24.2	34.4	4	3
Sample5	418	203.2	0.3	11.2	37.2	4	4
Sample6	418	203.2	0.3	11.3	37.2	3	3

The concrete structure analyzed has a cross-sectional area of 30*30 cm and a height of 3 meters. Reinforcement bars, as shown in Figure 10, are used to reinforce the concrete section. The stirrup spacing is 200 mm, and the stirrup cross-section dimensions are 250*250 mm. There are four longitudinal rebars used in both the beam and column sections.

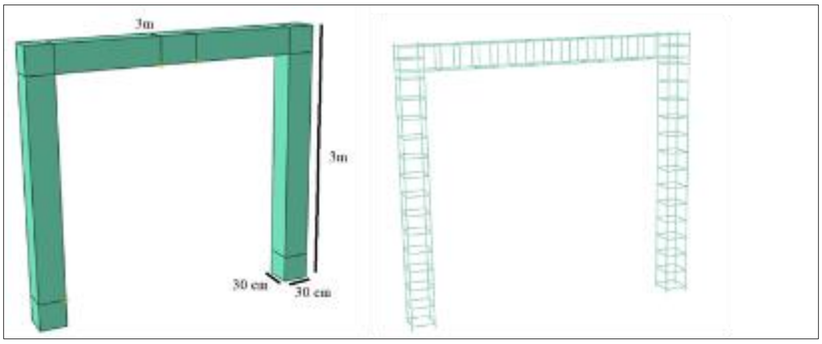


Figure 10 Geometry of the Concrete Section and Reinforcement Details Used in the Models

The geometry presented in Figure 1 has been used as the analyzed geometry in this study. According to Table 3, Model 1 represents the geometry without honeycomb cores. Model 2 has honeycomb cores with a wall thickness of 11.7 mm, consisting of 3 rows and 4 columns. Model 3 has a wall thickness of 11.8 mm with 3 rows and 4 columns. Model 4 features a wall thickness of 24.2 mm with 3 rows and 4 columns. Model 5 includes a wall thickness of 11.7 mm with 4 rows and 4 columns, while Model 6 has a wall thickness of 11.7 mm with 3 rows and 3 columns. In all models, the base of the columns is restrained, as shown in Figure 11, and explosive loading equivalent to 50 kg of TNT at a distance of 3 meters from each frame, following the protocol in Figure 12, is applied to the models.

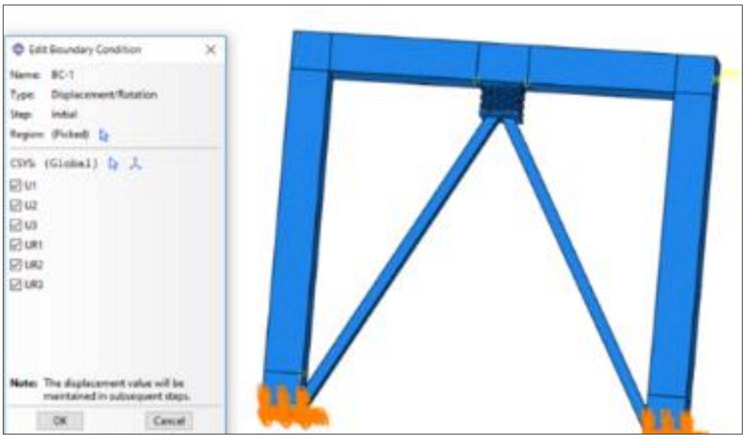


Figure 11 Restraint of Concrete Column Bases

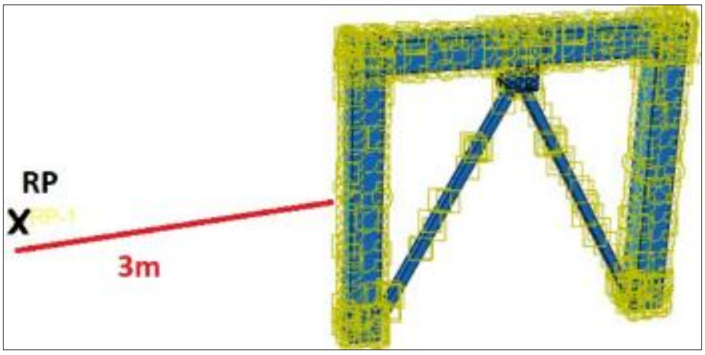


Figure 12 Distance and Location of Explosive Load from the Structure

3. Results and discussion

The results obtained in this study are presented in two sections. The first section includes the results related to the validation model analysis, and the second section presents the results of the explosive models analyzed.

3.1. Results Related to the Validation Model

In this section, the results related to the validation model analyzed in Abaqus software, which was explained in the previous section, are presented. The validation model under investigation was a honeycomb damper with three rows and four columns of honeycomb cells. The total length of the damper was 418 millimeters, and its width was 203.2 millimeters. The material of the damper was ASTM A360-17, and it was subjected to seismic loading. A comparison between the hysteresis curves of the results in this study and the article Reference Article [1] is presented in Figure 13.

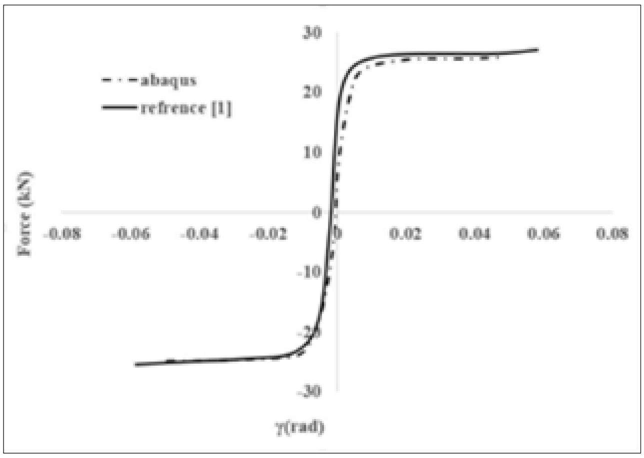


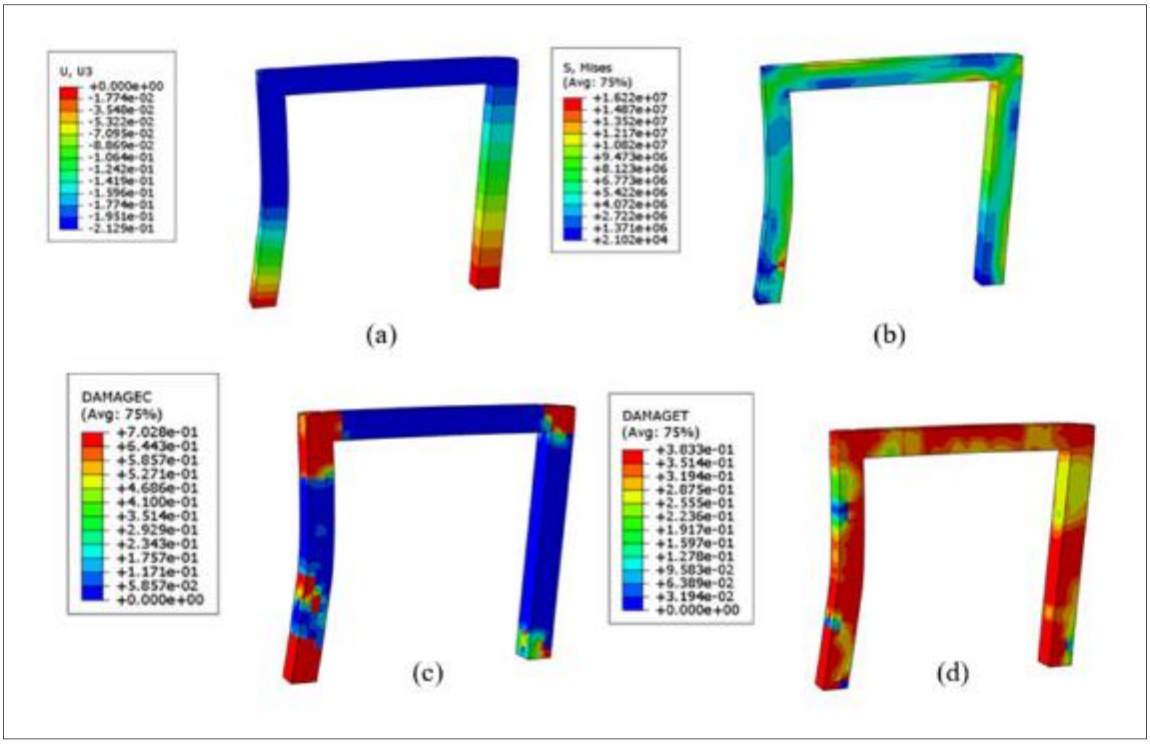
Figure 13 Comparison of Hysteretic Response Curves Obtained from Abaqus Analysis and the Reference Article [1]

As shown in Figure 13, the results obtained from the Abaqus analysis exhibit very good accuracy and are consistent with the results presented in the reference article by Yang and colleagues [1].

3.2. Results of Analyzed Models

3.2.1. Presenting Results for Model No. 1 (Concrete Frame Without Honeycomb Reinforcement)

In this section, the results related to the reinforced concrete frame model without honeycomb reinforcement, subjected to an explosive load of 50 kg of TNT, are presented. As previously mentioned, the load is applied 3 meters from the left side of the model. As a result of the explosive load, stress distribution, displacement, tensile, and compressive damages in the concrete are extracted and presented in Figure 14.



(a) Displacement Contours. (b) Stress Distribution Contours. (c) Compressive Damage Contours in Concrete. (d) Tensile Damage Contours in Concrete

Figure 14 Results for Model No. 1 (Concrete Frame Without Honeycomb Reinforcement)

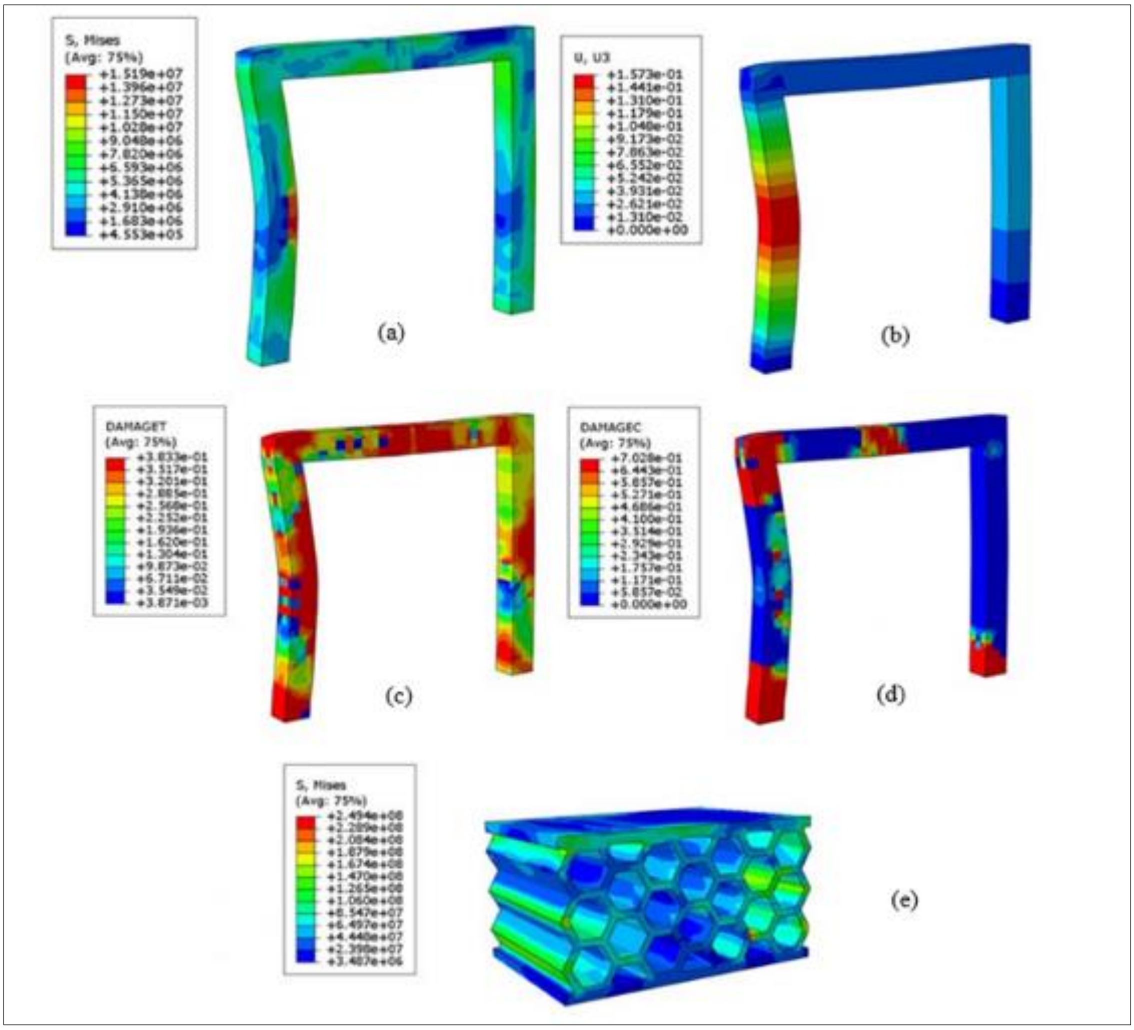
As shown in Figure 14 (b), the stress value in the concrete frame is 16.2 MPa and based on the compressive damage presented in Figure 14 (c), in the high-stress regions, the compressive damage has also reached the red-colored area, which is mostly in the beam-to-column connections and supports. According to the results shown in Figure 14 (d), the structure has experienced new tensile damage, and most areas have exceeded the tensile yield, indicating that the concrete frame has cracked.

3.2.2. Presenting Results for Model No. 2 (with a 4-row, 3-column damper, and a wall thickness of 11.2 mm)

In this section, the results related to Model 2 are presented. In this model, a reinforced concrete frame equipped with a shear wall and honeycomb cells has been analyzed. The shear wall used in this model has 4 rows, 3 columns, and a wall thickness of 11.2 mm. The results for stress, displacement, and contour plots of compressive and tensile damages in this model are presented in Figure 15.

As observed in Figure 15 (a), the maximum stress in the concrete frame is 15.1 MPa, which is lower than the maximum stress in Model 1, indicating that the presence of the honeycomb cells reduces the stresses compared to the model without the honeycomb cells. Furthermore, the high-stress areas in this model have decreased compared to Model 1, which was without any honeycomb cells, indicating that the use of honeycomb cells can effectively reduce the stresses generated in the concrete frame.

As shown in Figure 15 (b), the maximum displacement in this model due to the explosive load is 15.7 cm, which is 23% lower than the displacement in Model 1, where the displacement was 21.2 cm. This reduction in displacement is attributed to the use of both the confinement reinforcement and honeycomb cells in the model. Moreover, the results for the tensile and compressive damage contours reveal that using honeycomb cells in the concrete frame reduces the levels of tensile and compressive damage, primarily due to the lower stresses and displacements in the structure caused by the honeycomb cells.



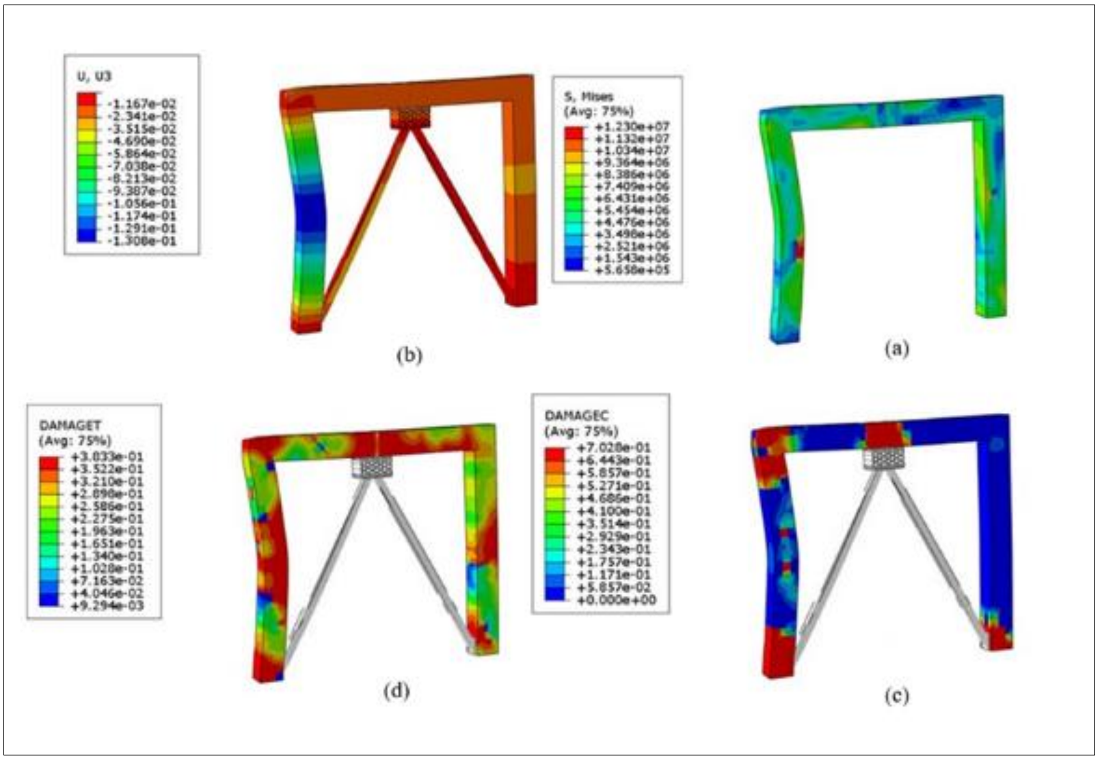
(a) Stress distribution contour. (b) Displacement distribution contour. (c) Tensile damage contour in concrete. (d) Compressive damage contour in concrete. (e) Stress distribution contour in the honeycomb cells

Figure 15 Presentation of results for Model No. 2 (with a 4-row, 3-column damper, and a wall thickness of 11.2 mm).

3.2.3. Presenting Results for Model No. 3 (with a 4-row, 3-column damper, and a wall thickness of 17.8 mm)

In this section, the results for Model 3 are presented. In this model, the honeycomb cells have been made thicker, with a wall thickness of 17.8 mm, compared to Model 2 where the wall thickness was 11.2 mm. Model 3 also features a honeycomb grid with 4 rows and 3 columns. The results for stress distribution, displacement, and damage contours in this model are shown in Figure 16.

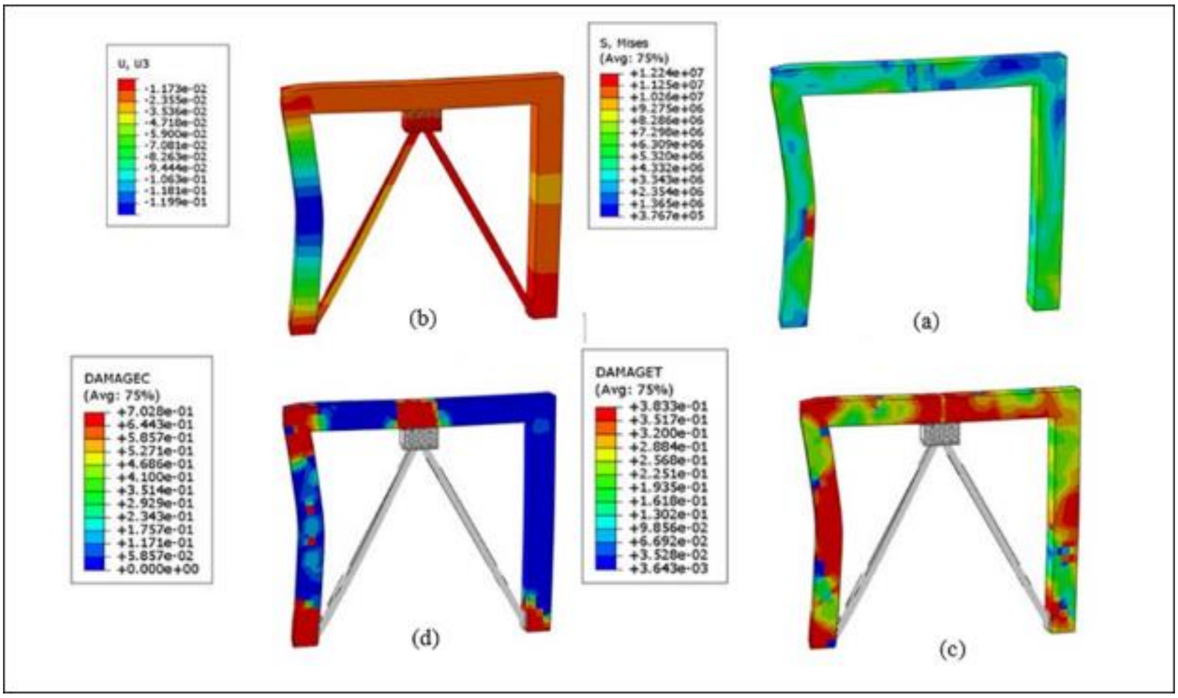
As shown in Figure 16 (a), the maximum stress in the concrete frame is 12.3 MPa, which is lower than the maximum stress in models 1 and 2. Also, the stress distribution in the honeycomb core has decreased. Therefore, by increasing the thickness of the honeycomb core walls, it is possible to reduce the maximum stress generated in the frame and honeycomb core. Furthermore, according to Figure 16 (b), the maximum displacement in this model due to the explosive load is 13 cm, which is lower compared to models 1 and 2. An important point in this model is that with an increase in the honeycomb core thickness, the absorbed energy in the honeycomb core increases. This leads to a 17% reduction in displacement compared to model 2, which had a thickness of 11.2 mm and a displacement of 15.7 mm. Additionally, based on the contour plots of tensile and compressive damage obtained in this section, it is evident that increasing the thickness of the honeycomb core results in a reduction of tensile and compressive damage in the concrete frame.



(a) Stress Distribution Contour (b) Displacement Distribution Contour (c) Compressive Damage Contour in Concrete (d) Tensile Damage Contour in Concrete.

Figure 16 Presentation of results for Model No. 3 (with a 4-row, 3-column damper, and a wall thickness of 17.8 mm)

3.2.4. Presentation of results related to Model No.4 (with a 4-row, 3-column damper, and a wall thickness of 24.2 mm)



(a) Stress Distribution Contour. (b) Displacement Distribution Contour. (c) Tensile Damage Contour in Concrete. (d) Compressive Damage Contour in Concrete.

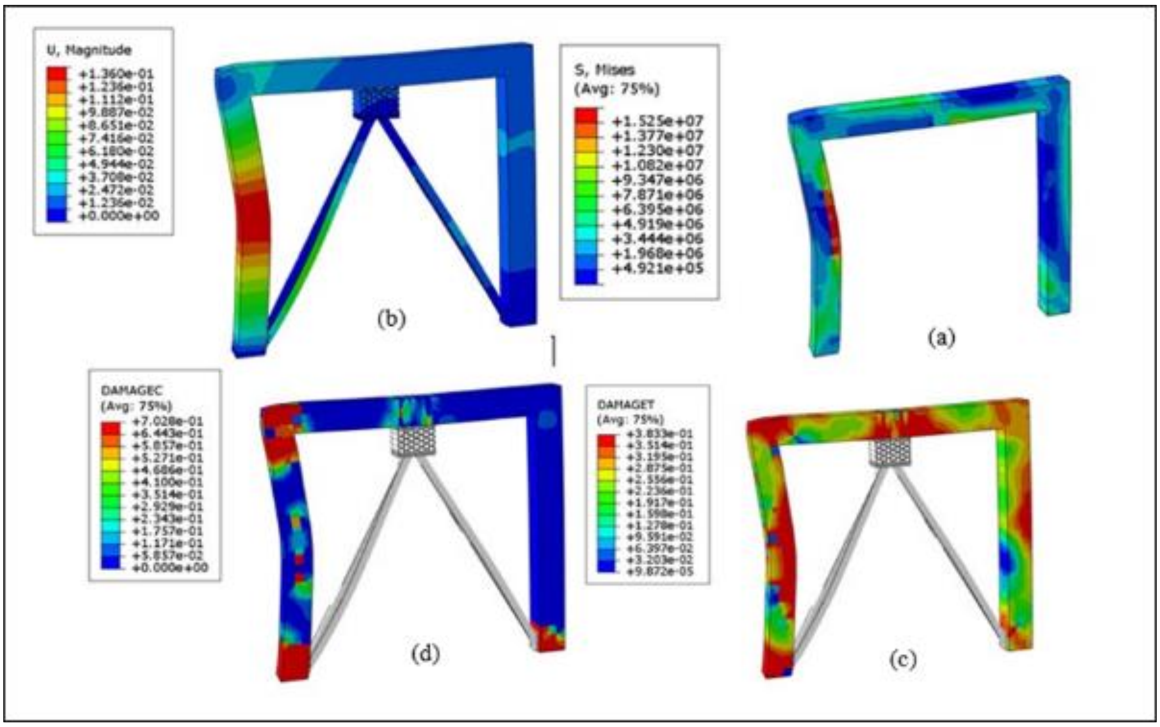
Figure 17 Presentation of Results for Model No. 4 (with a 4-row, 3-column damper, and a wall thickness of 24.2 mm)

In this section, the results related to Model Number 4 are presented. In this model, the thickness of the sensor grid for the honeycomb has increased compared to Models 2 and 3, reaching a thickness of 24.2 mm. The results related to displacement, stress, and contours of tensile and compressive damage in this sample are presented in Figure 17.

As shown in Figure 17 (a), the maximum stress value in the concrete frame is 12.2 MPa, which has not significantly decreased compared to Models 2 and 3. This is because the honeycomb damper has become very thick and close to a solid state, saturating its energy absorption capacity. The stress distribution in the damper has decreased slightly compared to Model Number 3, and the reason for this is the increase in its wall thickness. According to Figure 17 (b), the maximum displacement in this model due to the blast load is 11.7 cm, which has decreased compared to Models 2 and 3. This indicates that with increased thickness, this damper has been able to absorb more energy from the blast wave, resulting in a reduction in displacement. However, the decreasing trend in displacement in Models 2, 3, and 4 shows that beyond a certain thickness, an increase in thickness will lead to a decrease in displacement. This implies that the damper has become very thick, approaching a solid state, and its energy absorption capacity is saturated. Furthermore, based on the results obtained for tensile and compressive damage contours, it can be observed that an increase in the thickness of the honeycomb damper in the concrete frame did not significantly reduce tensile and compressive damage in the structural component compared to Model Number 3.

3.2.5. Presentation of Results for Model No. 5 (with a 4-row, 4-column damper, and a wall thickness of 11.2 mm)

In this section, the results related to Model Number 5 are presented. In this model, the wall thickness is the same as Model Number 2, at 11.2 mm, but the number of columns has increased from three to four. The model is subjected to the same blast load as Model Number 2, which is an explosive loading caused by a 50-kilogram TNT explosion. The results for displacement, stress, and damage contours in this model are presented in Figure 18. As seen in Figure 18 (a), the maximum stress in the concrete frame is 15.2 MPa, which is accompanied by a decrease compared to model number 2. Additionally, the stress in the honeycomb damper is also reduced compared to model number 2 with 3 columns. This indicates that increasing the number of columns can reduce the stress level in the structure. As shown in Figure 18 (b), the maximum displacement in this model due to the explosive load is 13.6 cm, which is a 14% decrease compared to model number 2 or three columns with a displacement of 15.7 cm. This suggests that increasing the number of columns can significantly reduce the displacement magnitude. Moreover, with an increase in the number of columns, the amount of compressive and tensile damage, especially in the structural pressure, decreases.



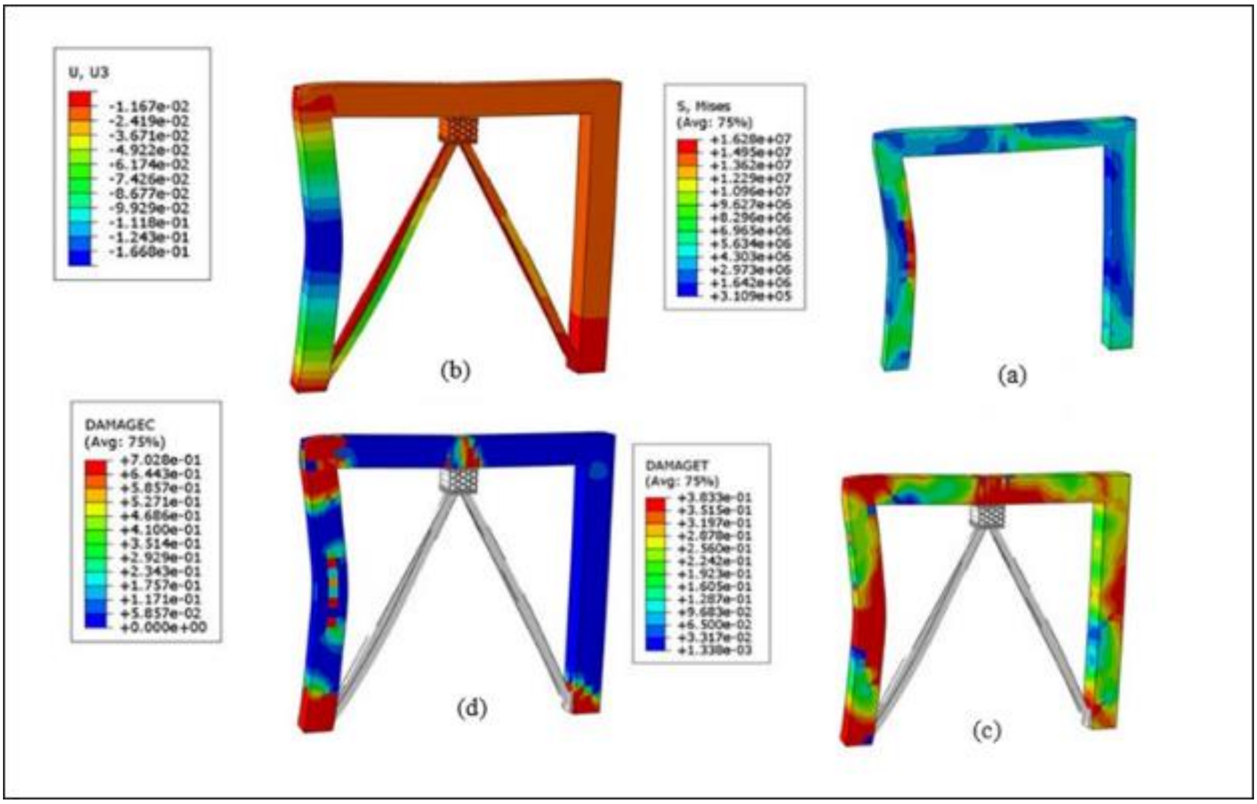
(a) Stress Distribution Contour. (b) Displacement Distribution Contour. (c) Tensile Damage Contour in Concrete. (d) Compressive Damage Contour in Concrete.

Figure 18 Presentation of Results for Model No. 5 (with a 4-row, 4-column damper, and a wall thickness of 11.2 mm)

3.2.6. Presentation of Results for Model No.6 (with a 3-row, 3-column damper, and a wall thickness of 11.2 mm)

In this section, the results related to Model Number 6 are presented. In this model, the wall thickness is the same as Model Number 2, at 11.2 millimeters, but the number of rows has been reduced from four to three to investigate the impact of reducing the number of columns on the behavior of the concrete frame under explosive loads. The results related to displacement, stress, and contours of tensile and compressive damage in this model are presented in Figure 19.

As shown in Figure 19 (b), the maximum displacement in this model due to the explosive load is 15.7 cm, which is 7% less than Model No. 2 with three rows, which had a displacement of 16.28 cm. This indicates that reducing the number of rows increases the displacement. As shown in Figure 18 (a), the maximum stress in the concrete frame is 16.28 MPa, which has increased compared to Model No. 2. Additionally, the stress in the honeycomb core is also higher compared to Model No. 2 with four rows, indicating that reducing the number of rows can reduce stress in the structure. Furthermore, as shown in Figures 19 (c) and 19 (d), reducing the number of rows slightly increases both compressive and tensile damage.



(a) Stress Distribution Contour. (b) Displacement Distribution Contour. (c) Tensile Damage Contour in Concrete. (d) Compressive Damage Contour in Concrete

Figure 19 Presentation of Results for Model No. 6 (with a 3-row, 3-column damper, and a wall thickness of 11.2 mm)

4. Conclusion

In this research, the behavior of a concrete frame with a honeycomb core under explosive loading has been investigated. Initially, a honeycomb core was subjected to seismic loading, and its hysteresis curve was extracted from the Abaqus software. After validating the results, a concrete frame with one span and one story, measuring 3 meters in height, was modeled in the Abaqus software, and equipped with a honeycomb core. This concrete frame was subjected to explosive loading generated by a 50-kilogram TNT explosion, placed at a distance of 3 meters from the left side of the structure. Displacements, stress distributions, and contour plots of tensile and compressive damage in the models were analyzed. In total, six models were subjected to explosive loading during this research. In the first model, the concrete frame was simple and had no honeycomb core, resulting in a displacement of 21.2 centimeters and a maximum stress of 16.2 MPa during the explosion. In the second model, a honeycomb core with 4 rows, 3 columns, and a wall thickness of 11.2 mm was placed in the reinforced concrete frame, and this frame was subjected to explosive loading again. The displacement in this model was 15.7 centimeters, and the maximum stress was 15.1 MPa. In the third model, the wall thickness of the honeycomb core from model 2 was increased from 11.2 mm to 17.8 millimeters. This change resulted in a displacement of 13 mm and a maximum stress of 12.3 MPa. In the fourth model, the wall thickness of the honeycomb core increased to 24.2 mm, resulting in a displacement of 11.7 centimeters and a maximum stress of 12.2 MPa. In the fifth model, the number of columns in model 1 increased from 3 to 4, while the thickness remained constant. This change led to a displacement of 13.6 centimeters and a maximum stress of 15.7 MPa. In the final model, the number of rows in model 2 decreased from 4 to 3, resulting in a displacement of 16.28 mm and a maximum stress of 28.1 MPa. From the results obtained in this research, the following conclusions can be drawn:

Increasing the wall thickness of the honeycomb core with a constant number of rows and columns will reduce displacement, maximum stress, and tensile and compressive damage in the reinforced concrete frame equipped with a honeycomb core. Increasing the number of columns in the honeycomb core will result in reduced displacement, stress, and tensile and compressive damage in the model. Decreasing the number of rows in the honeycomb core will lead to increased displacement, stress, and tensile and compressive damage in the model. These findings provide valuable insights into optimizing the design of concrete frames with honeycomb cores under explosive loading, contributing to enhanced structural performance and safety.

References

[1] Yang, T. Y., Li, T., Tobber, L., & Pan, X. (2020). Experimental and numerical study of honeycomb structural fuses. Engineering Structures, 204, 109814.

[2] Zadeh, S. S., Joushideh, N., Bahrami, B., & Niyafard, S. (2023). A review on concrete recycling. World Journal of Advanced Research and Reviews, 19(02), 784–793. https://doi.org/10.30574/wjarr.2023.19.2.1631.

[3] Kiani, B. K., & Hashemi, B. H. (2021). Development of a double-stage yielding damper with vertical shear links. Engineering Structures, 246, 112959.

[4] Safavigerdini, K., Nouduri, K., Surya, R., Reinhard, A., Quinlan, Z., Bunyak, F., ... & Palaniappan, K. (2023). Predicting mechanical properties of Carbon Nanotube (CNT) images Using Multi-Layer Synthetic Finite Element Model Simulations. arXiv preprint arXiv:2307.07912.

[5] S. B. Ferdosi, M. Porbashiri, (2022). Calculation of the Single-Walled Carbon Nanotubes' Elastic Modulus by Using the Asymptotic Homogenization Method, International Journal of Science and Engineering Applications 11, 254–265. DOI: 10.7753/IJSEA1112.1002.

[6] Najmi, L., Zebarjad, S. M., & Janghorban, K. (2023). Effects of Carbon Nanotubes on the Compressive and Flexural Strength and Microscopic Structure of Epoxy Honeycomb Sandwich Panels. Polymer Science, Series B, 1-10.

[7] Ferdosi, S. B. (2023). Thermal Effect on The Post-buckling And Mechanical Response of Single-Walled Carbon Nanotubes: A Numerical Investigation. Mechanical Engineering, 9, 1-6.

[8] P, Arabi., Zadeh, S. S. (2023). The Environmental Impact of Anti-Icing Materials on Asphalt Surfaces (Commonly Used Anti-Icing Agents) Environ. Eng., 9 (2023), pp. 1-4. 10.52547/crpase.9.2.

[9] Mohammed Ali, A., Besharat Ferdosi, S., Kareem Obeas, L., Khalid Ghalib, A., & Porbashiri, M. (2023). Numerical study of the effect of transverse reinforcement on compressive strength and load-bearing capacity of elliptical CFDST columns. Journal of Rehabilitation in Civil Engineering, 12(1).

[10] Kiani, B. K., Torabian, S., & Mirghaderi, S. R. (2015). Local seismic stability of flanged cruciform sections (FCSs). Engineering Structures, 96, 126-138.

[11] Jung, W. Y., & Aref, A. J. (2003). A combined honeycomb and solid viscoelastic material for structural damping applications. Mechanics of Materials, 35(8), 831-844.

[12] Motamedi, M., & Nateghi-A, F. (2004, August). Using accordion thin-walled tube as a hysteretic metallic damper. In 13th World Conference on Earthquake Engineering, Vancouver, Canada.

[13] Chan, R. W., & Albermani, F. (2008). Experimental study of steel slit damper for passive energy dissipation. Engineering Structures, 30(4), 1058-1066.

[14] Oh, S. H., Kim, Y. J., & Ryu, H. S. (2009). Seismic performance of steel structures with slit dampers. Engineering structures, 31(9), 1997-2008.

[15] Heidari, P. S., Kayhani, H., & Jazany, R. A. (2012). Introducing a new hysteretic metallic damper using circular jagged plates. In Proceedings of the 1st Makassar International Conference on Civil Engineering (MICCE2010), Makassar, Indonesia.

[16] Zheng, J., Li, A., & Guo, T. (2015). Analytical and experimental study on mild steel dampers with non-uniform vertical slits. Earthquake Engineering and Engineering Vibration, 14(1), 111-123.

[17] Teruna, D. R., Majid, T. A., & Budiono, B. (2015). Experimental study of hysteretic steel damper for energy dissipation capacity. Advances in Civil Engineering, 2015.

[18] Teruna, D. R., Majid, T. A., & Budiono, B. (2015). Numerical Models of Hysteretic Steel Damper with a Hollow Diamond Shape for Energy Dissipation. In Applied Mechanics and Materials (Vol. 802, pp. 243-248). Trans Tech Publications Ltd.

[19] Naeem, A., Lee, M., & Kim, J. Steel Honeycomb Dampers for Seismic Retrofit of Structures, 2015.

[20] He, H., Wang, X., & Zhang, X. (2016). Energy-dissipation performance of combined low yield point steel plate damper based on topology optimization and its application in structural control. Advances in Materials Science and Engineering, 2016.

[21] Lee, M., Lee, J., & Kim, J. (2017). Seismic retrofit of structures using steel honeycomb dampers. International Journal of Steel Structures, 17(1), 215-229.

[22] Lee, J., & Kim, J. (2017). Development of box-shaped steel slit dampers for seismic retrofit of building structures. Engineering Structures, 150, 934-946.

[23] Farrokhnia, N., & Movahedifar, S. M. Investigating the behavior of steel structures with honeycomb damper against blast and earthquake loads.