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The Numerical Investigation of Steel Structural Members with Various Web Opening Shapes Under Impact Load Effects

Çeşitli Göz Açıklıklı Çelik Yapı elemanlarının Darbe Yükü Etkisi Altında Sayısal Olarak İncelenmesi

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Abstract

In this study, the influence of different web-opening shapes on the impact performance of steel structural elements was evaluated numerically using ABAQUS. IPE240 profiles were modeled with circular, hexagonal, pentagonal, square, and triangular openings, keeping material properties, opening area, number, and placement identical. The 3D models used C3D4 elements, and two lateral impact scenarios were applied: loading on the flange and on the web. Load–deflection behavior and deformation patterns were analyzed. Results indicated that opening geometry significantly affects strength loss. Triangular openings produced the greatest reduction, while circular and hexagonal shapes performed best. Overall, although the presence of openings decreases the impact resistance of the profiles, certain geometries can preserve structural behavior more effectively than others.

Keywords: *Steel structural element, Web opening shapes effect, Impact load, Numerical modeling.*

Öz

Bu çalışmada, farklı geometrik şekillerdeki göz açıklıklı çelik yapı elemanlarının darbe yükü altındaki performansı ABAQUS sonlu elemanlar programı kullanılarak sayısal olarak incelenmiştir. IPE240 profilleri, malzeme özellikleri, açıklık alanı, sayısı ve yerleşimi aynı tutularak dairesel, altıgen, beşgen, kare ve üçgen açıklıklarla modellenmiştir. 3B modellerde C3D4 elemanları kullanılmış ve iki yanal darbe senaryosu uygulanmıştır: başlık bölgesine yükleme ve gövde bölgesine yükleme uygulanmıştır. Analizlerden Yük-Deplasman eğrileri ve deformasyon davranışları elde edilmiştir. Sonuçlar, açıklık geometrisinin mukavemet kaybını önemli ölçüde etkilediğini göstermiştir. Üçgen açıklıklar en büyük azalmayı sağlarken, dairesel ve altıgen şekiller en iyi performansı göstermiştir. Genel olarak, açıklıkların varlığı profillerin darbe direncini azaltmasına rağmen, bazı geometriler yapısal davranışı diğerlerine göre daha etkili bir şekilde koruyabilir.

Anahtar Kelimeler: *Çelik yapı elamanı, Boşluk etkisi, Darbe yükü, Sayısal modelleme.*

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1. Introduction

Steel structures are widely used in engineering applications due to their advantages, including a high strength-to-weight ratio, ductility, rapid assembly, and modular design flexibility. The safe and efficient operation of these structures depends on several key parameters, including geometry, loading type, connection details, environmental conditions, and material properties. Openings, particularly in web areas, are preferred both to reduce the weight of the structure and to allow for installation passages. However, such openings can reduce section stiffness and load-bearing capacity, increasing the risk of buckling, fatigue, and local collapse.

Impact-like loading represents sudden dynamic forces such as vehicle collisions, falling objects, or other accidental actions acting on structural members. In structural analysis, these loads may be applied in several forms. Lateral impact on the flange involves a force applied perpendicular to the flange surface, typically simulating external collisions and leading to local flange deformation accompanied by global bending of the beam. Lateral impact on the web is applied directly to the web region, which is particularly critical for castellated beams because the presence of openings creates stress concentrations that may initiate local buckling or distortion. Impact loads can also be modeled as concentrated loads, applied at a specific node or small contact area to represent point collision events, or as distributed loads, applied over a larger area or through a rigid impactor surface to simulate more realistic contact interaction conditions [1].

In recent years, engineering research has focused on understanding the effects of openings of different shapes, sizes, and locations in steel members on structural behavior. Lawson [2] proposed a detailed design method based on the distribution of the internal forces around a rectangular opening. Abbas [3] used ABAQUS to show the significant effect of various opening geometries on energy absorption and deformation behavior, comparing with experimental results. Rodrigues et al. [4] reported the effect of different shape of the steel beams with web openings and benefits of using an adequate edge concordance radius in beams with rectangular and square openings. Impact loads induce both elastic and plastic behavior by creating a sudden, high-energy loading condition in the structure. Numerical and experimental studies conducted in recent years have developed methodologies, particularly for impact resistance analysis. Studies on built-up battened columns have comprehensively demonstrated the response of columns under axial compression to lateral cyclic load and their failure modes [5]. Finite element models used in applications such as flight/vehicle impacts produce highly accurate results when applied with software suitable for dynamic solutions (e.g., ABAQUS/Explicit); this approach has also been validated by experimental data [6–7].

In modern analyses under axial and lateral loading, energy absorption, deformation modes, and damage mechanisms can be evaluated in detail, and design parameters can be optimized for steel members, using both experimental tests and finite element methods. Experimental and numerical studies conducted by different researchers showed that the deformation and damage processes of steel beams under impact loading can be successfully modeled in the ABAQUS finite element program [8–11]. Rate- and temperature-dependent plasticity models (Johnson–Cook) are widely preferred for accurately describing material behavior under high-speed loading [12]. The behavior of steel structures under dynamic loads has been extensively investigated in numerous studies. The Johnson and Cook [12] material model is widely used because it realistically represents the plasticization, temperature increase, and speed-dependent behavior of steel structural elements under high-speed loading. Al-Sultan and Al-Rifaie [13] numerically investigated steel beams with large web openings (SBLWOs) under impact load. Živaljevic et al. [14] analyzed the failure mechanisms of cold-formed steel (CFS) members with web holes subjected to pure compression, bending, web crippling and shear and compared them with experimental results. Zeinoddini et al. [15] investigated the lateral impact effects on axially loaded steel tubes experimentally and numerically. Gültop et al. [16] reported an analytical investigation of rigid plastic beams under impact loading. Zhang et al. [17] reported the behavior of circular steel tubes subjected to low-velocity transverse impact. Wang et al. [18] noted that compared to the experimental results, the theoretical method provides reasonable predictions on the impact force and the global deflection response for the cement composite filled pipe specimens.

Some researches emphasized that impact velocity, mass, and impact location are decisive factors in structural response. Geometric shape details also play a significant role in impact behavior [19-20]. Hashm et al. [21] analyzed the impact of various parameters, including the beam's geometry, and boundary conditions, on the dynamic behavior of castellated beams. Creating different geometric openings (mesh openings) in steel structures provides advantages such as reducing structural weight, increasing energy dissipation capacity, and aesthetic diversity. However, these openings have significant effects on stiffness, local buckling behavior, and under-impact deformation characteristics. Albayati et al. recently in three different studies have focused on optimizing the structural performance of castellated steel beams using advanced metaheuristic algorithms. The first study investigated castellated beams with hexagonal web openings and optimized their section dimensions by minimizing maximum vertical displacement using the Flower Pollination Algorithm (FPA), Firefly Algorithm (FA), and Bat Algorithm (BA), concluding that FPA and FA produced similar results while FPA was most suitable for engineering applications. The second study also optimized castellated beams based on maximum vertical deflection using Gray Wolf Optimization (GWO), Particle Swarm Optimization (PSO), and Differential Evolution (DE) for materials S235, S255, and S355, finding that PSO and DE generated very similar and reliable outcomes while GWO showed slightly different results. The third study extended the optimization concept to sinusoidal castellated beams and proposed a multi-criteria framework using five metaheuristic algorithms—Cyclical Parthenogenesis Algorithm (CPA), Improved Ray Optimization (IRO), Tug of War Optimization (TWO), Vibrating Particles System (VPS), and Imperialist Competitive Algorithm (ICA)—considering cost, processing time, dimensional consistency, and solution stability. The results indicated that CPA and TWO provided robust and cost-efficient solutions, VPS achieved the lowest cost for longer spans, and span length was the most influential factor affecting optimization performance [22-24].

Numerical studies on beams with large web openings reveal that the hole shape, ratio, and arrangement have a significant impact on maximum deflection, carrying capacity, and energy absorption The different effects of circular, square, and pentagonal mesh openings on forced vibration and deflection amplitudes in honey comb beams have also been demonstrated [25]. The effects of perforations in thin-walled/cold-formed members, directly reflected in the design method, have been reported in the context of local and global buckling and carrying capacity [26]. It is also emphasized that section discharge and sharp corner effects in plates increase stress concentrations and trigger the first plasticization zones [27-28]. While circular openings, thanks to their symmetry, can provide a more homogeneous deformation distribution under impact by keeping stress concentrations relatively low, square or polygonal openings can exhibit stress concentration and premature deformation in corner areas.

Therefore, in openings, the shape, size, and layout are critical design parameters not only for lightweighting and architectural requirements but also for structural performance under impact [29–31]. Design standards impose limitations on opening dimensions and layouts. AISC 360-22 [32] recommends that web openings should not exceed 50–70% of the beam height and should be kept away from high-moment zones. Eurocode 3 (EN 1993-1-1) [33] limits web openings to maintain shear capacity, while TBDY 2018 [34] does not allow section loss in plastic hinge regions and limits the openings in columns.

This study aims to investigate the effect of opening geometry on the behavior of steel structural members under impact loads. The dynamic behavior of 3200 mm long IPE 240 steel profiles under impact loading was investigated using the finite element method (FEA). The aim is to investigate the impact of various opening shapes and locations on the beam's load-bearing capacity, deformation profile, and energy absorption properties, to obtain findings that will contribute to the development of design criteria. The study will apply the Johnson–Cook material model to three-dimensional models created using ABAQUS/Explicit software, and compare the impact load responses of different opening scenarios.

2. Material and Methods

In this study, the finite element method (FEA) (Abaqus/Explicit) was used to analyze the dynamic behavior of steel structures under impact loads. This selection was made considering the software's superior capabilities in nonlinear dynamic problems, its extensive material model support, and its validity in the literature. This software offers reliable solutions to complex structural problems that involve large deformations, nonlinear material behavior, and high deformation rates. In particular, during sudden and high-energy loadings such as impact, stability can be achieved in time-dependent analyses thanks to the explicit solution algorithm. This feature is crucial for accurately modeling the high-velocity plastic deformations investigated in this study. In terms of material model support, ABAQUS/Explicit can effectively apply the Johnson–Cook plasticity model [12] to describe the behavior of steel at high deformation rates.
This model allows for accurate simulation of material behavior under impact by accounting for strain hardening, strain rate sensitivity, and thermal softening effects. The reliability of ABAQUS program in impact analyses has been confirmed in numerous studies in the literature. This constitutes a significant reference supporting the software's suitability for this study. In conclusion, ABAQUS/Explicit's advanced dynamic analysis capabilities, comprehensive material models, and widespread use in the literature were decisive factors in its selection, as it is well-suited for this study.

The Johnson–Cook yield model was used to describe the behavior of the steel structure in the models. This model is renowned for its accurate representation of material behavior, particularly at high deformation rates. The steel material properties were defined as modulus of elasticity (210 GPa), yield strength (235 MPa), and density (7850 kg/m³) (Table 1). A time step of 0.001 seconds was selected for the dynamic analyses, allowing for a detailed study of the structure's response to the sudden load.

Table 1. For the steel (S235) material; Value of density, Modulus of elasticity and Poisson's ratio

Density (kg/mm³)	**Modulus of elasticity** (Mpa)	**Poisson's ratio**
7.85×10^{-6}	210000	0.30

The Johnson–Cook model is dependent on strain, strain rate, and temperature, and these dependencies become more pronounced during impact. Therefore, material description is a critical element for the success of impact analysis.

$$\sigma_y = (A + B\varepsilon_p^n)(1 + C \ln \dot{\varepsilon}^*) \tag{2.1}$$

Therefore, the Johnson-Cook yield criterion was used as the material model (Figure 2):

- A (Yield Stress): 235 MPa (S235 material, TS EN 10025-2).
- B (Hardening Coefficient): 680 MPa.
- n (Hardening Base): 0.73.
- C (Deformation Rate Sensitivity): 0.008.

Johnson and Cook proposed a constitutive model and data for metals under large strains, high strain rates, and high temperatures. These parameters realistically represent the behavior of steel under high-speed loading conditions [12].

Table 2. Definition of steel material Johnson-Cook plastic parameters in the Abaqus program

A	**B**	**n**	**m**	**Melting Temp**	**Transition Temp**
235	680	0.73	0.008	1500	725

2.1. Geometry Models

In the modeling, a steel structure with an IPE 240 profile, a length of 3200 mm, a height of 240 mm, a flange thickness of 9.2 mm, and a web thickness of 6.2 mm was drawn (Figure 1). The center point of this structural element was positioned to coincide with the origin of the coordinate system. In addition to the gapless case, the cross-sections were also considered to be circular, hexagonal (honeycomb), equilateral pentagonal, square, and equilateral triangular shapes. The gaps were spaced in four equal areas at fixed intervals. The opening geometries were created under homogeneous dimensional and spatial conditions to comparatively examine the effects on structural rigidity, deformation behavior, and energy dissipation capacity.

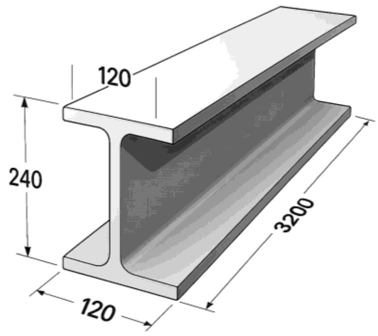

Figure 1. Steel structure model (IPE240) dimensions (mm)

The length, width, and thickness of the steel structural element were kept constant in all models, and the number, area, and location of openings were determined at equal intervals. All structural elements were modeled in three dimensions. The total opening area (every five openings) was kept constant at 8.02% of the drilled surface area (surface area 61623.08 / 768.00 mm^2) and distributed at equal intervals (640 mm) throughout the structure. Thus, the following geometric openings were placed symmetrically in the web areas of the steel structural elements (Figure 3).

Table 3. Length and area measurements of different opening shapes used in the design

Opening Shape	Side Length/ Diameter (mm)	One Opening Area (mm^2)
IPE 240 with Circular Opening	140.04 (Diameter)	15405.77
IPE 240 with Square Opening	124.12	15405.77
IPE 240 with Triangle Opening (Equilateral)	188.57	15405.77
IPE 240 with Pentagon Opening (Equilateral)	94.59	15405.77
IPE 240 with Hexagonal Opening (honeycomb)	124.7	15405.77

The non-opening (Reference model) was preferred due to its homogeneous stress distribution (Figure 2). Similarly, circular openings were selected due to their homogeneous stress distribution, while square and triangular openings were chosen to investigate stress concentrations at the corners. Equilateral hexagonal (Honeycomb) and pentagonal openings were used to investigate the effect of the number of -20.6% corners.

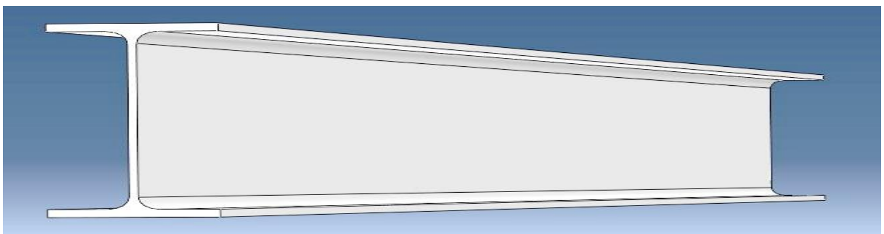

Figure 2. Non-opening steel structure model -IPE 240

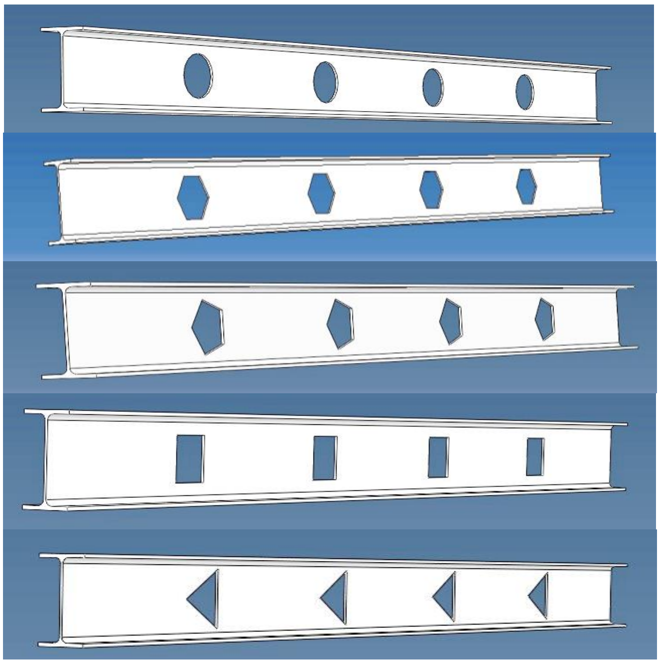

Figure 3. (a) Circle; (b) Hexagon (Honeycomb); (c) Equilateral pentagon; (d) Square; (e) Equilateral triangle; opening steel structures model-IPE 240

2.2. Definition of Support Conditions and Impact Load

In this study, the two ends of the structural element were defined with a fixed support condition. This boundary condition allowed for a clearer observation of the flexural behavior of structures subjected to lateral impact loads and represented a realistic structural system. The applied load was defined as uniformly distributed across the flange and web regions and applied as a time-varying dynamic (impact) load. The impact function, magnitude, and duration were calibrated to be compatible with the Johnson–Cook model, and the loading scenario was selected to represent realistic effects such as vehicle impact, explosion, or sudden impacts [12]. Thus, the energy dissipation and deformation behavior of opening structures were comparatively analyzed.

Lateral impact loading was performed on IPE240 steel profiles. These 240 mm-high profiles are a section commonly used as a beam or column element in structural systems. The impact load was applied to the lateral surface of the profile to evaluate its performance under sudden loading. The analysis was conducted with an idealized impact load. In real-world applications, impact loads typically have more complex time histories. Furthermore, detailed modeling of the material's strain-rate and damping parameters increased the accuracy of the results, providing a closer representation of the actual system behavior. The load was defined as a rectangular shape with a 1-unit amplitude over a time interval of 0.01–0.05 s (See Figure 4). The model was developed assuming that lateral torsional bending was avoided.

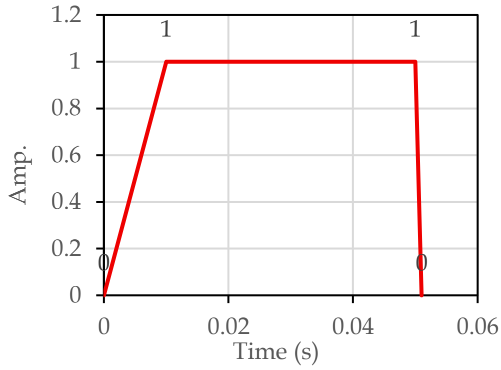

Figure 4. Lateral impact load function graph

The applied lateral impact load was modeled using time history analysis in ABAQUS. The lateral impact load was applied as two different loading types to the flange and web regions, as shown in Figures 5 and 6.

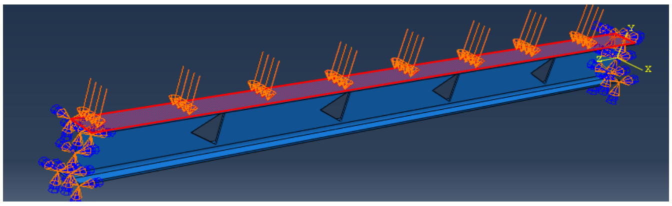

Figure 5. Lateral impact load applied to the flange section of the models

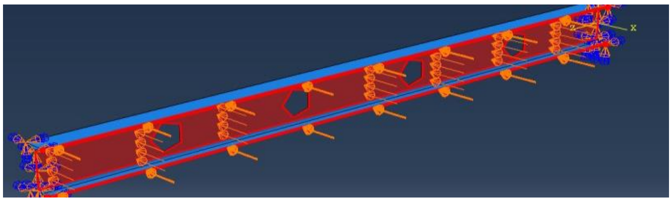

Figure 6. Lateral impact load applied to the web section of the models

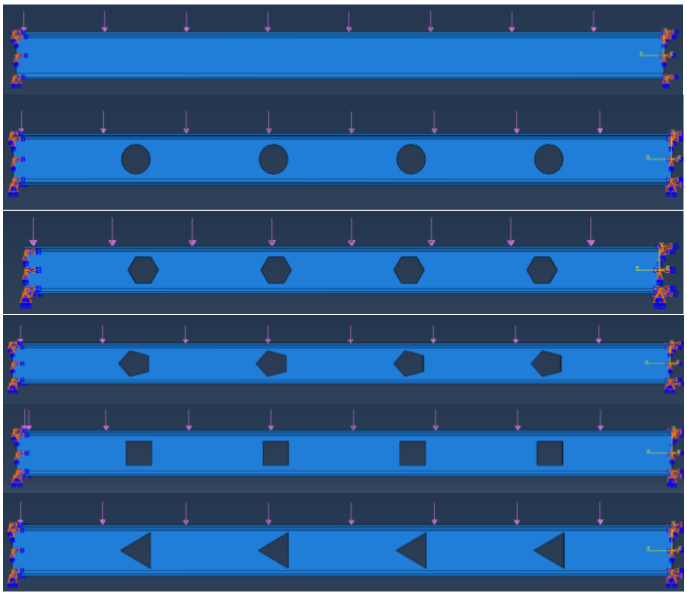

Figure 7. Illustration of the impact load applied to the flange section in six different models

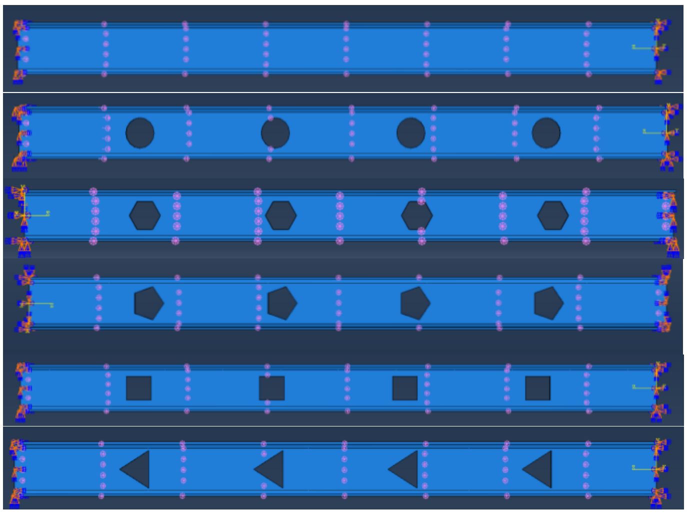

Figure 8. Illustration of the impact load applied to the web section in six different models

2.3. Definition of Mesh and Finite Elements

When creating the finite element mesh, smaller elements were used in the structure's open areas because it was anticipated that stress concentrations would be more intense in these areas. Larger elements were chosen for the global mesh structure to optimize computational time. The element type used was four-node linear volumetric 3D solid elements (C3D4), known for their stability under impact loading. Mesh quality was maintained at the same resolution (Approximate global size) of 10 for each model and tetrahedral element type with technique free mesh was applied to ensuring reliable comparisons between analyses. Meshed images of structural elements with openings of various shapes, including circular, hexagonal, pentagonal, square, and triangular, are shown in Figure 9.

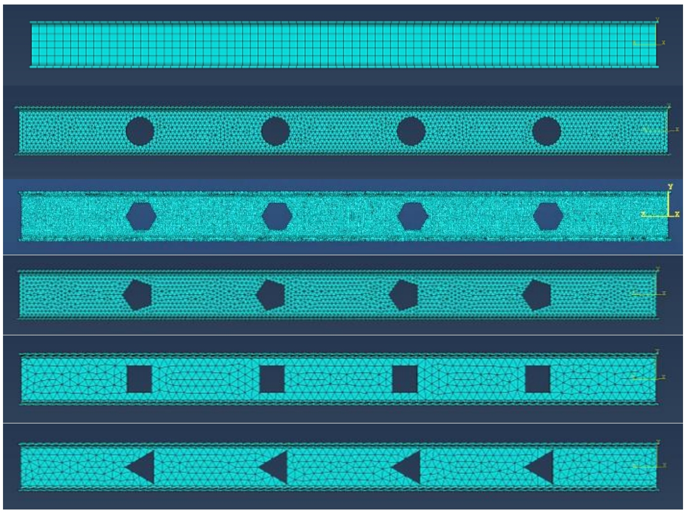

Figure 9. Meshed images of structural elements with non-opening, circular, hexagonal, pentagonal, square, and triangular openings

2.4. Analysis Steps and Definition

The numerical analyses were carried out using a time-dependent dynamic analysis step in ABAQUS. Initially, the system was brought to equilibrium, after which a short-duration impact load was applied to the structural model. The time increment was automatically controlled by the solver to maintain numerical stability during the simulation. At the end of the analysis, parameters such as maximum deflection, stress distribution, and plastic strain were extracted to evaluate the influence of different opening geometries on the structural response.

3. Results and Discussion

In the analyses, each structural model was subjected to the same impact loading conditions under identical boundary constraints. The results allowed a detailed evaluation of the dynamic response of the IPE240 profile under lateral impact loading, including the identification of critical deformation regions and strength limitations. Furthermore, the findings provided insight into the structural performance of the profiles under sudden loading conditions, particularly regarding their ductile behavior and the extent of permanent deformation.

3.1. Impact Load Applied to the Flange Section

Figure 10 below shows the stress distribution results for all specimens after the lateral impact load analysis applied to the flange section. The non-opening structural element model here is designed to be 3200 mm long, 120 mm high, and 240 mm wide, serving as a reference for impact load resistance. The other specimens have four (4) equal/equilateral openings placed at equal intervals in the web section, the opening areas and properties of which are given in Table 3. All structural element models were modeled and analyzed to have the same material properties, dimensions, and boundary conditions.

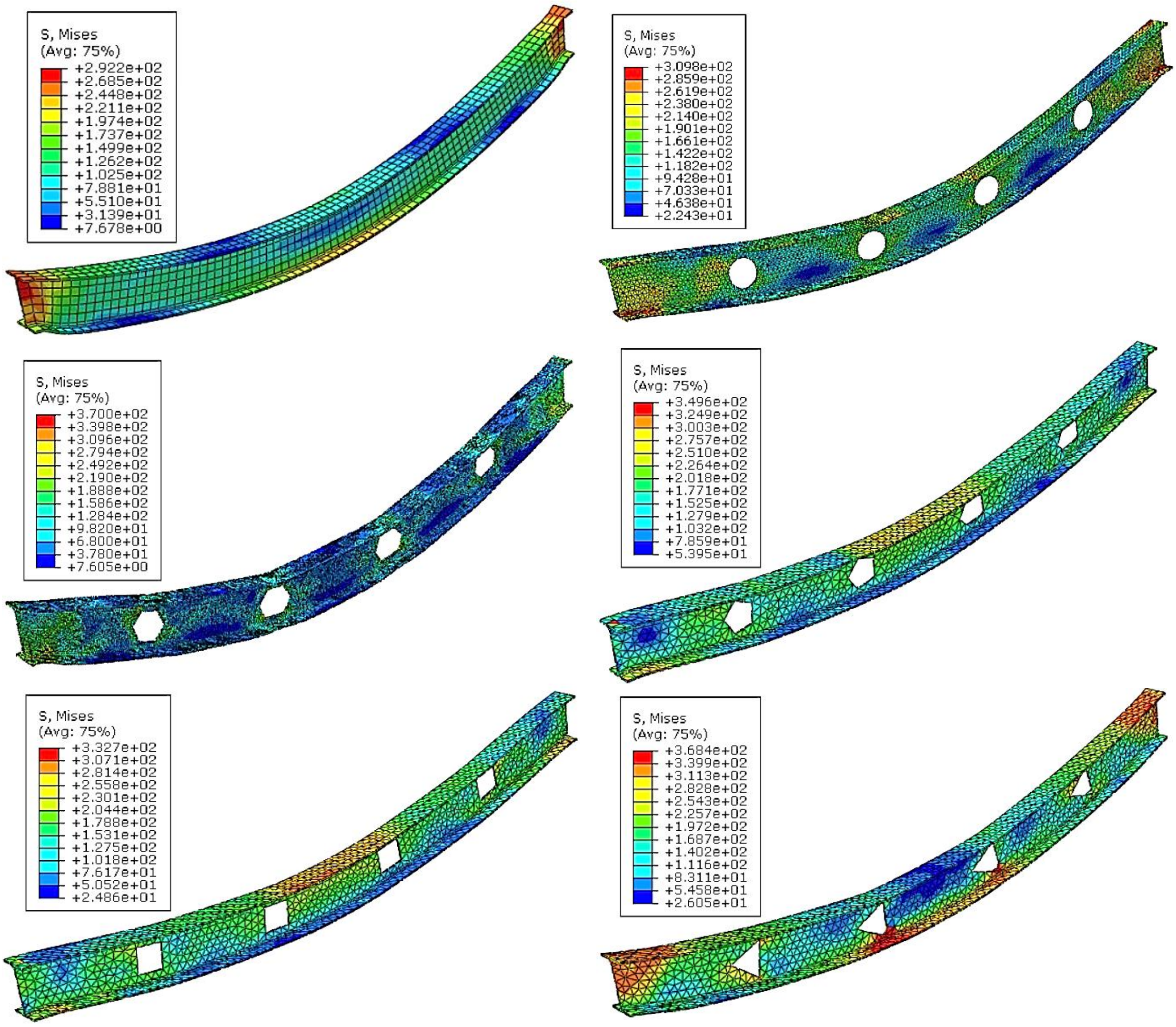

Figure 10. Stress (MPa) distribution results after lateral impact load analysis applied to the flange sections of structural element specimens with different opening geometries

Figure 11 presents the Load-Deflection curves and peak values of these curves resulting from the application of lateral impact load to the flange section of the steel structural element according to the non-opening and different opening types.

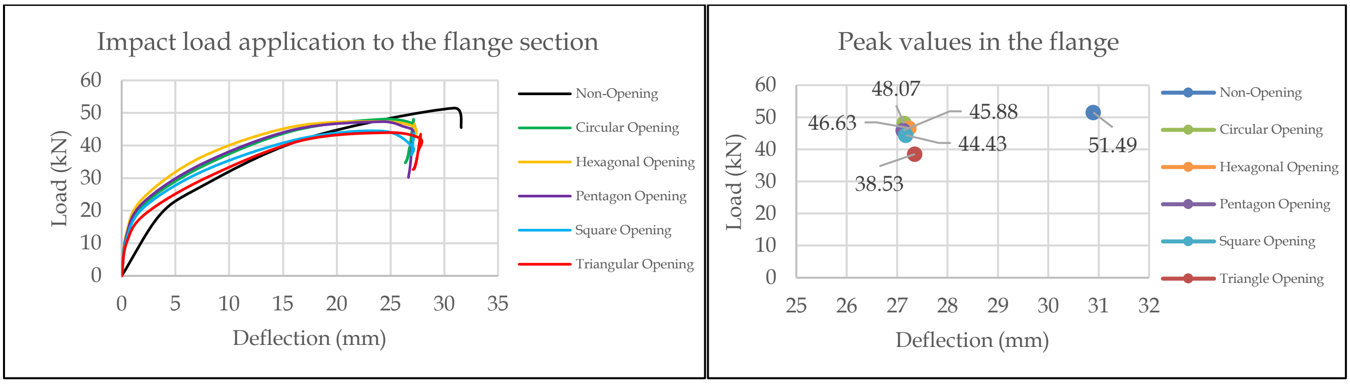

Figure 11. Load-Deflection curves and peak values formed by applying lateral impact load to the flange sections of the steel structural element according to the non-opening and different opening types

3.2. Impact Load Applied to the Web Section

When the impact load was applied to the web section of the structural elements, similar to the flange section, the results were obtained as shown in Figures 12 and 13. The models here also have the same material properties, dimensions, opening numbers and areas, and boundary conditions, and were analyzed using the finite element method.

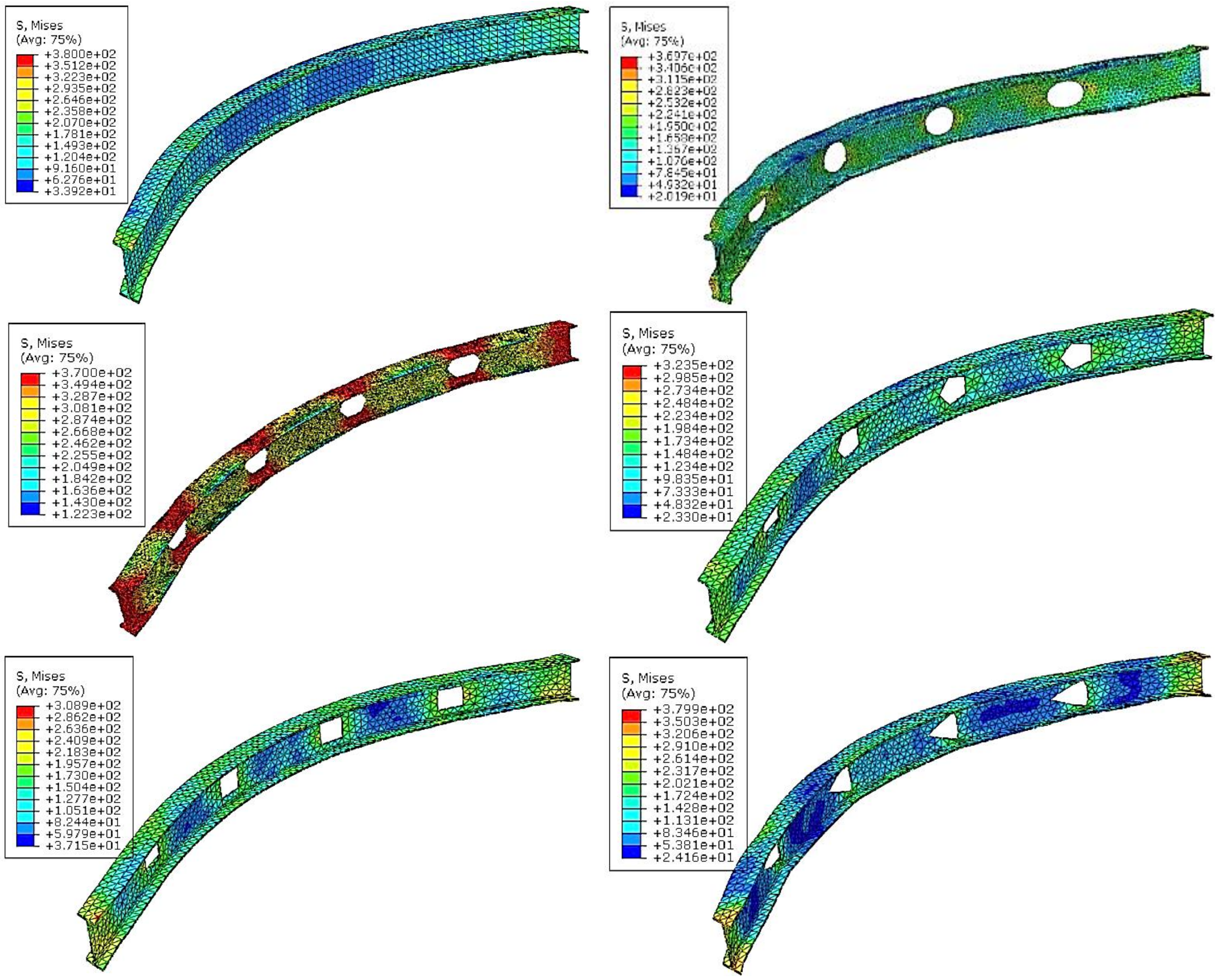

Figure 12. Stress (MPa) distribution results after lateral impact load analysis applied to the web sections of structural element specimens with different opening geometries

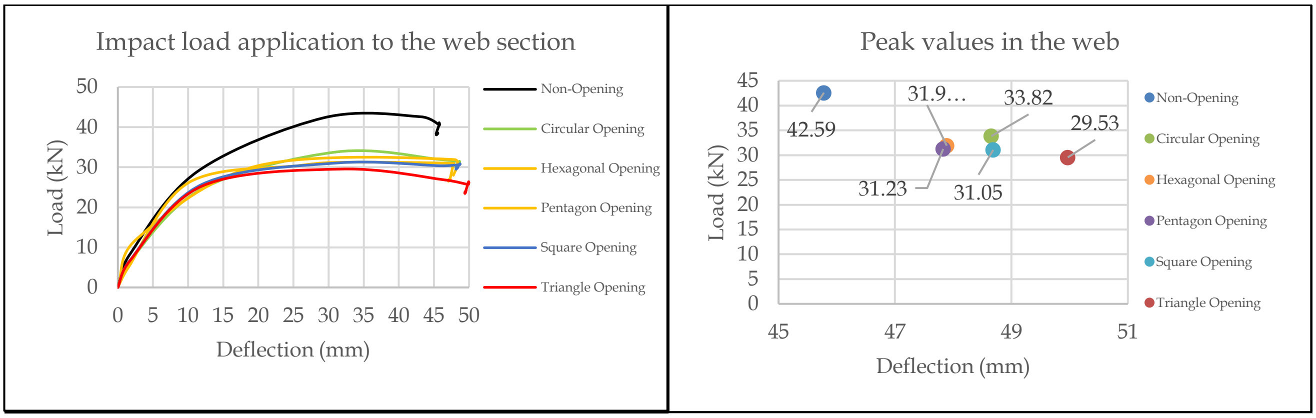

Figure 13. Load-Deflection curves and peak values formed by applying lateral impact load to the web sections of the steel structural element according to the non-opening and different opening types

Overall, the data obtained reveal that opening geometry significantly affects the structural response of steel structural members to lateral impact loads applied to the flange and web regions. While non-opening models offer the most advantageous solutions in terms of bearing capacity and controlled deformation, circular opening specimens stand out as the opening shape that maintains this performance with minimal loss. Angular and pointed openings, on the other hand, lead to a more uneven distribution of deformation, local stress concentrations, and consequently, lower bearing capacity and greater deformation. All these considerations demonstrate that opening shapes in the design of structural systems subject to impact should be carefully considered not only for visual or ease of manufacture but also for structural performance.

The values presented in Table 4 provide direct guidance in engineering design in this context. According to the results obtained, when applying the scenario to the flange section, the circular opening model has a carrying capacity loss of 6.64%, followed by the hexagonal, pentagonal, square, and triangular opening models with losses of 25%, 26.67%, 27.1%, and 25.17%, respectively. Similarly, when examining the scenario applied to the body section, the circular opening model exhibits a carrying capacity loss of 30.66%, followed by the hexagonal, pentagonal, square, and triangular opening models, with losses of 9.44%, 10.89%, 13.71%, and 25%, respectively.

Table 4. Comparative Assessment of Lateral Impact Behavior in Flange and Web Sections

Section	Model	F_{max} (kN)	% Strength Change by Flange	% Strength Change by Web	Δ_{max} (mm)	Behavior Summary
Flange	Non-Opening	51.49	----	----	30.89	Highest rigidity and bearing capacity
Flange	Circular Opening	48.07	-%6.64	–	27.14	Homogeneous deformation spread; stable plasticity, minimum loss of carrying capacity
Flange	Hexagonal Opening (honeycomb)	46.63	-%9.44		27.24	Behavior between circle and pentagon, low loss of carrying capacity
Flange	Pentagon Opening (Equilateral)	45.88	-%10.89	–	27.12	High deformation; local bending risk, moderate loss of carrying capacity
Flange	Square Opening	44.43	-%13.71	–	27.18	Stress concentration due to the corner effect; medium stiffness behavior, loss of carrying capacity is very high
Flange	Triangular Opening (Equilateral)	38.53	-%25.17	–	27.35	Stress concentration at sharp corners; risk of premature yielding, greatest loss of carrying capacity
Web	Non-Opening	42.59	----	----	45.78	Balanced rigidity in the body area and the Highest bearing capacity
Web	Circular Opening	33.82	–	-%20.6	48.65	Plastic deformation propagation; medium rigidity, minimum loss of carrying capacity
Web	Hexagonal Opening (honeycomb)	31.90		-%25	47.89	Low loss of carrying capacity, behavior between the circle and the pentagon
Web	Pentagon Opening (Equilateral)	31.23	–	-%26.67	47.83	Medium load-bearing capacity loss, low rigidity
Web	Square Opening	31.05	–	-%27.1	48.68	Loss of carrying capacity is high, local deformation at corners, and poor rigidity
Web	Triangular Opening (Equilateral)	29.53	–	-%30.66	49.97	Lowest bearing capacity, accumulation of deformation at sharp corners

4. Conclusion

The study in question is about a fixed-fixed simple castellated beam under impact loading, to evaluate the impact effects under realistic boundary conditions. Unlike conventional studies that primarily focus on static loading conditions, this research specifically examines the impact response of steel profiles containing different web opening geometries, thereby providing deeper insight into the structural performance of perforated beams under sudden dynamic loads. The novelty of this study lies in the comparative evaluation of multiple opening geometries (circular, hexagonal, pentagonal, square, and triangular) under lateral impact loading conditions, which has been rarely addressed in the literature.

As a result of the analysis:

i. It was observed that the applied impact load caused large deflections in a short time, with maximum deflections occurring in the middle region, primarily due to the lateral impact load applied to the web section.

ii. When the stress distributions were examined, it was determined that concentrations occurred in the corner and joint regions of the profile, and these regions exhibited critical behavior.

iii. By evaluating the plastic deformation thresholds, it was determined that the profile exhibited ductile behavior; however, permanent deformations were inevitable when certain load levels were exceeded.

iv. According to the results obtained, when the scenario applied to the flange section is considered, there is a loss of carrying capacity of 6.64% in the circular opening model, followed by 25%, 26.67%, 27.1% and 25.17% in the opening models with hexagonal, pentagonal, square, and triangular geometry, respectively.

v. Considering the scenario applied to the web section, there is a loss of carrying capacity of 30.66% in the circular opening model, followed by 9.44%, 10.89%, 13.71% and 25% in the opening models with hexagonal, pentagonal, square, and triangular geometry, respectively.

vi. In summery under flange impact, circular openings caused only a 6.64% drop in capacity, whereas triangular ones led to a 25.17% loss. For web loading, capacity loss ranged from 20.6% (circular) to 30.66% (triangular). Overall, although all openings reduce impact resistance, circular and hexagonal shapes preserve structural performance more effectively than triangular configurations.

vii. When considering geometric diversity and symmetry, the selected opening shapes vary in terms of symmetry and circumferential regularity as the number of vertices increases. This creates different effects on load transfer, stress accumulation, and deformation behavior. In this context, a systematic improvement in structural response is observed with the transition from triangular to circular shapes.

The results highlight the importance of accurately identifying critical areas in the design of steel members subjected to impact loads. Furthermore, the findings can be considered as a guide for earthquake-resistant design and for improving structural safety against vehicle impacts or explosions.

Future studies are recommended to model impact loads with more complex time histories, consider the effects of strain rates in detail, and conduct comparative studies of different steel profiles. Furthermore, this study only evaluated profiles derived from the IPE 240 section type; comparisons can be made across different section types (e.g., HEA, HEB) or different support conditions.

Contribution Statement

Research design, literature review and evaluation, data collection, data analysis, validation of data and analysis, interpretation of findings, and writing of the article were all done by Arman Atasoy.

Conflict of Interest Statement

The author of the article declares that he has no personal or financial conflict of interest with any institution, organization or person.

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