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RESEARCH ARTICLE

# Investigating the behavior of hollow steel section beam under repetitive transverse impact loading

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## Abstract

When a load is exerted on a structural element several times, it is called repetitive loading. This type of loading causes more damage to structural elements than monotonic loading. This paper presents the effects of repetitive transverse impact loading on the weak axis of rectangular hollow steel section beam. For this purpose, three simply supported beams were tested with a constant drop weight of 75 kg and three different heights (400 mm, 800 mm and 1200 mm). Transverse impact load was exerted on each specimen 3 times repeatedly. In the numerical studies, finite element models of all specimens were developed using ABAQUS finite element analysis software. In order to obtain reliable numerical models, finite element models were verified using the experimental data. To investigate the effects of repetitive transverse impact loading on hollow section steel beam, parameters such as displacement, reaction forces, stress distributions and out of plane plastic denting were evaluated comparatively. The obtained results showed that, when the height value is increased twice as the initial height in test series RIA and RIB, the displacement value increased by 57% in the first hit, 68% in the second hit and 79 % in the third hit. Thus, it seems that the increase in the displacement value due to the increase in the damage of subsequent hits is not linear, but rather logarithmic. Finally, it was understood that with increase in the plastic deformation and displacement occurring in an element subjected to repeated impact loading, a decrement occurs in the reaction force transferred to the supports.

## 1. Introduction

Many engineering structures can be subjected to different static and dynamic loads throughout their lifetime. Loads with dynamic characteristics that cause structural elements to reach their limit state such as an earthquake may be less likely to happen over the years, but it may occur from repeated loads that occur many times during the day. Repetitive loads to which structural members are exposed can be vehicles passing over a bridge, cargo loads placed on steel frames with forklifts, rockfall on tunnel structures and glacial masses hitting on ships and offshore structures.

Today, the rapid melting of Arctic Ocean ice due to global warming causes the ice floes to disintegrate. Due to the climatic characteristics of the region, glacier fragments can have many and different sizes. These ice pieces cause the ships and pier structures used in maritime transportation of the countries in the Arctic

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Ocean region to be exposed to repeated impact loading. Such scenarios cause a low velocity repetitive impact load on the structural member. Therefore, plastic deformations occur in the element, which can pose significant threats to the safety of structural elements or ships. Determining the value of strength as a result of plastic deformations in structural elements, subjected to repetitive impact loads poses a vital problem for vessels carrying gas in these regions [1]. Even if the repetitive impact forces are very small magnitude, they can accumulate over time and reach a certain level. This situation can cause plastic deformations and sudden collapses in the building elements. Many studies have been conducted to investigate the effects of repeated impact loading on composite element [2], steel plate members [3-5] and steel reinforced concrete columns [6]. However, there has not been much work done on the behavior of steel beam elements under the effect of repeated impact loading.

There is a difference between the deformation of the element exposed to repeated impact loads with the same energy and the deformation value that occurs in the element exposed to a single impact force with the same energy. This difference is called the critical level pseudo-shakedown phenomenon. Many studies have been carried out to investigate the effect of the pseudo-shakedown phenomenon [7, 8]. When a literature review is done, it seems that researchers studied the behavior of beam [9, 10] column [11-13] and large diameters steel tube [14] under single impact loading. In addition, the effects of single impact load in low velocity [15], high velocity [16], elements with different boundary condition [17] and impact heads with different geometry [18] on beam element were investigated.

The plastic deformation caused by the repeated impact force and the residual stresses of the previous impacts are effective in the behavior of the structural element. Permanent deformations cause a decrease in the moment of inertia and strength of the element. Especially in structural elements in cold polar regions or in offshore structures. In addition to repeated impact loads, the temperature effects that the structural elements are exposed to are important [1, 19-23]. The dynamic response of a structure subjected to repeated impacts includes many components. Therefore, many experimental studies are required. Because the experimental studies are difficult and many variables are effective in repeated impact loading; The verification of the finite element modeling with the data obtained from experimental study is important for further studies and many parametric studies can examine the behavior of the building elements under different conditions [2,3, 17-19, 22].

In this study, the behavior of rectangular hollow steel beam under repeated impact loads was investigated experimentally and numerically. The displacement-time graphs obtained from the experimental study were used to validate the finite element models. Stress in the beam, plastic denting, support reaction forces and damage conditions on the verified finite element models were investigated comparatively.

## 2. Experimental studies

To investigate the behavior of rectangular hollow steel beam under repeated impact loading, 3 steel beam profiles having 2000 mm length and 80×80×3 mm dimensions have been used in experimental studies. The specimens were prepared in the laboratory with a steel grade of S275JR. In the experimental impact loading, impactor with a height of 400 mm, 800 mm and 1200 mm, with the same geometric head and the same weight (75 kg), was released into free fall on the mid-point of the steel beam. In the first impact loading, the hammer was dropped from 400 mm to the first sample. Then the hammer was raised to a height of 400 mm again, and the second stroke was made on the deformed specimen and this process was repeated 3 times for each specimen from heights of 400 mm, 800 mm and 1200 mm, respectively. The boundary conditions of the test specimen were not changed between the repetition of the impact loading. The details of the experimental specimen and impact loadings are given in Table 1.

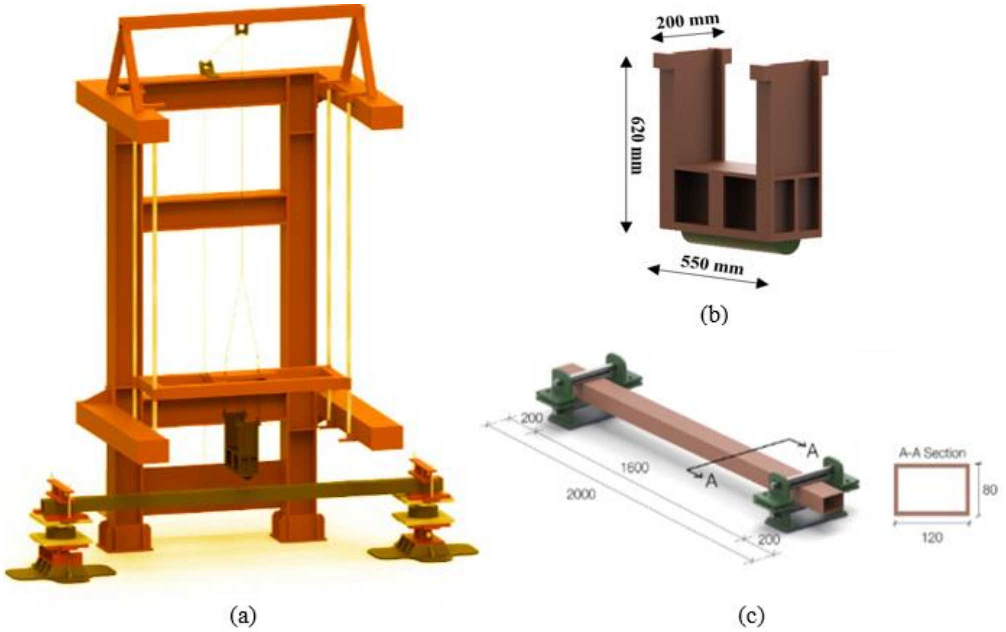



Fig. 1. Schematic view of (a) experimental test set up, (b) impactor's dimensions and (c) specimen dimensions and boundaries conditions

Table 1. Properties of test specimens

| Codes | | Number of Repeated Impact | Dimensions (mm) | Length (mm) | Cross section (mm²) | Drop height (mm) | Hammer weight (kg) |
|---|---|---|---|---|---|---|---|
| Specimen A | RIA-1 | 1 | 120×80×3 | 2000 | 1140 | 400 | 75 |
| | RIA-2 | 2 | 120×80×3 | 2000 | 1140 | 400 | 75 |
| | RIA-3 | 3 | 120×80×3 | 2000 | 1140 | 400 | 75 |
| Specimen B | RIB-1 | 1 | 120×80×3 | 2000 | 1140 | 800 | 75 |
| | RIB-2 | 2 | 120×80×3 | 2000 | 1140 | 800 | 75 |
| | RIB-3 | 3 | 120×80×3 | 2000 | 1140 | 800 | 75 |
| Specimen C | RIC-1 | 1 | 120×80×3 | 2000 | 1140 | 1200 | 75 |
| | RIC-2 | 2 | 120×80×3 | 2000 | 1140 | 1200 | 75 |
| | RIC-3 | 3 | 120×80×3 | 2000 | 1140 | 1200 | 75 |

The test set up height of the hammer which exerted the repat impact loading was adjusted to vary from 100 mm to 2000 mm, but only 3 different heights were used in the study as shown in Table 1. The circular head geometric shape hammer used in the experiment weighed 75 kg, and the weight and geometry of the load were kept constant in all samples used in the experiment. The hammer weighing 75 kg was lifted to a height of 400 mm, 800 mm and 1200 mm by electric hydraulic jack and the point at which the hammer would hit the sample was determined by a digital meter. In addition, there were shafts that prevent the load from bouncing and damaging the environment during free fall. The displacement meter and accelerometer were placed at the point where the hammer hit the sample. The accelerometer was mounted to the test sample by welding with special steel apparatus. While placing the accelerometers in the sample, care was taken to ensure that the accelerometer was in the direction the load hammer fell. While testing the samples, the data obtained from the accelerometers were collected on the computer with the data collector and the obtained data were processed with the help of computer programs. In addition, a partial foundation of 500 mm depth and 2000 mm width was constructed under the test setup in order to absorb the vibration in the sample during the experiment. The supports in the test setup were designed as pin and sliding. The test specimen was fixed between the supports and the drop load was adjusted to hit the middle part of the specimen. The accelerometer used in the test setup could read acceleration up to ±5000 g. The data received from the accelerometers were taken with the help of NI 9234 cable. A load cell with a capacity of 200 tons (CAS LSU) was used to measure the support reactions in the test sample. The displacement value in the study was obtained by integrating the acceleration values obtained from the accelerometer placed in the middle of the test sample. In addition, the reaction force values were obtained from the load cell mounted on the support.

## 3. Numerical studies

Numerical analyses were conducted using the ABAQUS software, which is widely used for simulating the experimental conditions under repetitive impact loading. For the actual experiment, an impact load was applied using a 75 kg hammer, dropped from three different heights: 400 mm, 800 mm, and 1200 mm. Each height was tested with three repetitive impacts to assess the behavior and effects on the rectangular hollow steel beam. To capture the intricacies of stress distribution, plastic deformation, and reaction forces, three finite element models were developed based on these experimental setups (Fig. 2).

The stress-strain data of the material was first converted into its true stress-strain format and then input into the ABAQUS software. The conversion was executed using Eqs. (1) and (2), where, εT is true strain, εnom is engineering strain, σT is true stress, and σnom is engineering stress [24].

$$\sigma_T = \sigma_{eng}(l + \varepsilon_{eng}) \quad (1)$$

$$\varepsilon_T = ln(l + \varepsilon_{eng}) \quad (2)$$

In this study, an elastoplastic stress-strain curve, earlier validated by Nasery et al. [18] was used for the material of the steel beam. Key material parameters, such as Poisson's ratio and Young's modulus, were set at 0.3 and 175.73 GPa, respectively. Table 2 presents mechanical properties of the steel are provided.

In order to obtain sensitive results in all parts of the steel beam in the finite element analysis, the beam and impactor were modeled as 3D solid elements. An eight-node linear C3D8R element was used as the element type of the numerical models.

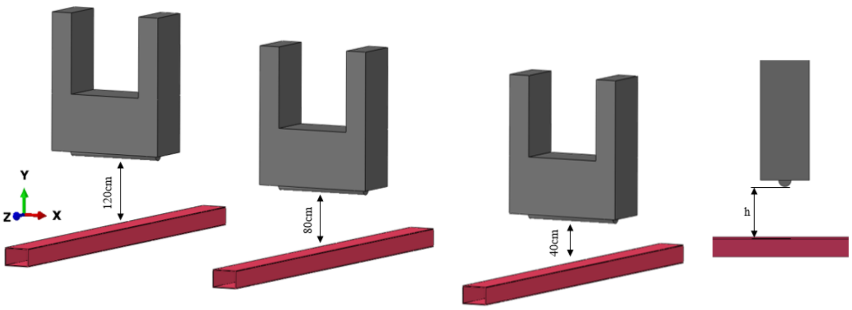



Fig. 2. Finite element models for three different heights of the impact loading

Table 2. Mechanical properties of steel material [18]

| Material | Yield Stress (MPa) | Tensile Strength (MPa) | Elastic Modulus (GPa) | Rupture Ratio (%) |
|---|---|---|---|---|
| Steel | 273.93 | 391.76 | 175.73 | 24.25 |

Meshing which is a crucial feature in FEA, largely determines the accuracy of results. Several mesh sensitivity studies have been explored by Nasery et. al [18] to determine balance between computational efficiency and result accuracy. Since steel beams with similar dimensions were used in this study, the mesh dimensions were chosen similar to the aforementioned study and analyses were carried out. Fig. 3 illustrates the meshed 3D finite element model of the rectangular hollow steel beam and impactor. Strain rate effects are key material parameter when the finite element simulation of the elements is analyzing under impact loading. However, strain rate effects are insignificant at initial impact velocities ($V_o$) under 10 m/s [25,26]. In this study, all specimens have been examined under the initial velocity of 5m/s, therefore, the strain rate effects of steel material have been ignored in the numerical studies.

## 4. Results and discussions

### 4.1. Experimental results

The experimental setup with the same boundary conditions was used in order to evaluate the results obtained from the experimental study correctly. In addition, the hammer size, geometric features, weight, impact force and sample size were all kept constant (only the heights being the parameters) for better comparison of the results.

For the purpose of the study, the effect of the previous impact force did not change in the repeated impact force applied to the 3 test samples. In the all three-test specimen used in the experimental study, the maximum displacement value was formed in the area where the hammer first contacted the sample. The obtained displacement-time and reaction force-time histories for all specimen are given in Fig. 4.

The maximum displacement value, shown as Series C, was obtained as a result of the hammer being dropped from the maximum height (1200 mm). Therefore, the displacement value in the element directly depends on the height at which the hammer is dropped. When the experimental study results of RIA-1 (400 mm height) and RIB-1 in which the height value was doubled (800 mm height), were examined, the displacement value increased by 57%. Similarly, when the experimental study results of RIA-2 and RIB-2 and RIA-3 and RIB-3 samples were examined, the displacement value increased by 68% and 79%, respectively. Thus, it was understood that, as impact force is height distance is doubled, the displacement value increases between 57-79% in repetitive impacts. In addition, when the impact force increases, more damage occurs to the element in the first hit comparing to the subsequent hits.

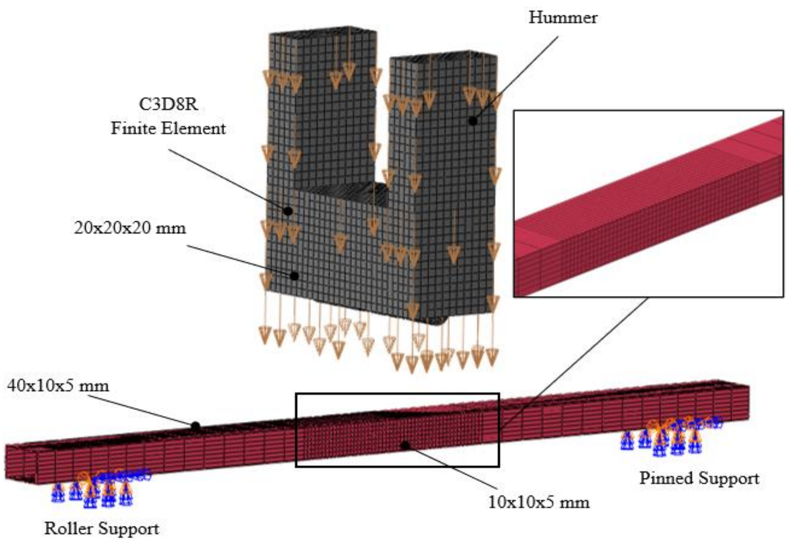



Fig. 3. 3D view of meshed finite element model of the rectangular steel beam and impactor

Finally, it has also been observed that the displacement values due to damage of repetitive impacts do not increase linearly, but rather logarithmically.

In Series RIA, RIB and RIC, the displacement values at first and second hits were greater than the third hit. In serial RIA; the displacement value increased by 38% at the second hit, comparing to 26% at the third hit. As for the RIB series; the displacement value in the second hit increased by 45%, and 35% in the third hit. Lastly, the displacement value in RIC increased by 67% in the second hit comparing to 49% in the third hit. Therefore, the plastic deformation that occurs in the element as a result of the third impact is not as much as in the second impact. This means that by increasing the plastic deformation of the section, the amount of impact energy absorbed by the section does not completely transfer to the outside of the section.

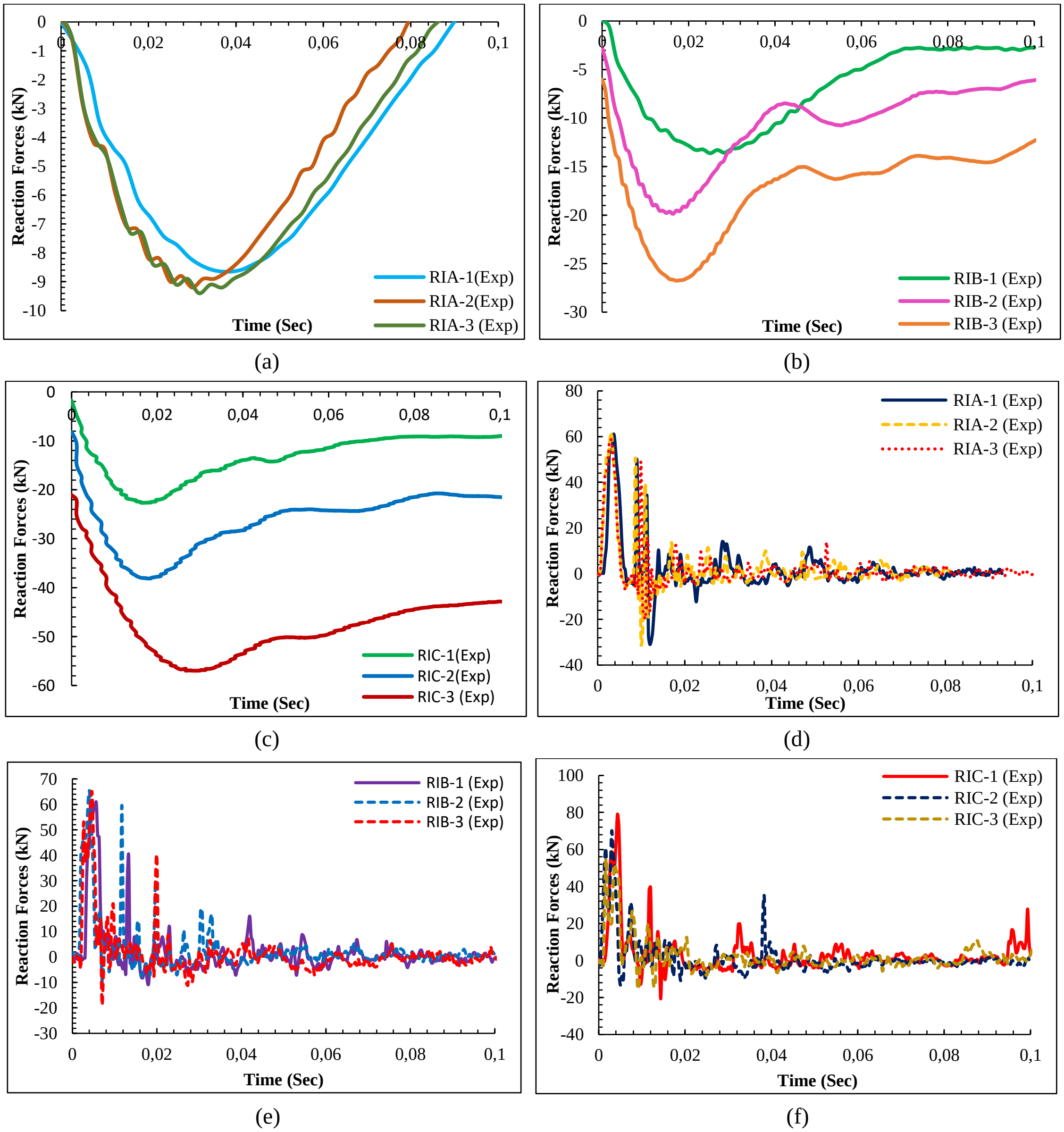



Fig. 4. Experimental results of displacement-time histories of test series (a) RIA, (b) RIB, (c) RIC, and the reaction force-time histories for test series (d) RIA under 400 mm, (e) RIB under 800 mm and (f) RIC under 1200 mm of height of impactor

When the reaction forces-time graphs are examined in the RIA series, the maximum reaction force obtained on the second hit was 1.16% less compared to the first hit, while a 5.10% lower value was obtained in the third hit compared to the second hit. In the RIB series, there was a 1.2% decrease in the second hit compared to the first hit, and a 5.25% decrease in the third hit compared to the second hit. In the RIC series, the maximum reaction forces obtained in the second hit was 13.04% less than the reaction forces obtained in the first hit, while this decrease was 26.81% in the third hit compared to the second hit. Accordingly, with the increase in the plastic deformation and displacement occurring in an element subjected to repeated impact loading, a decrease is observed in the reaction force transferred to the supports.

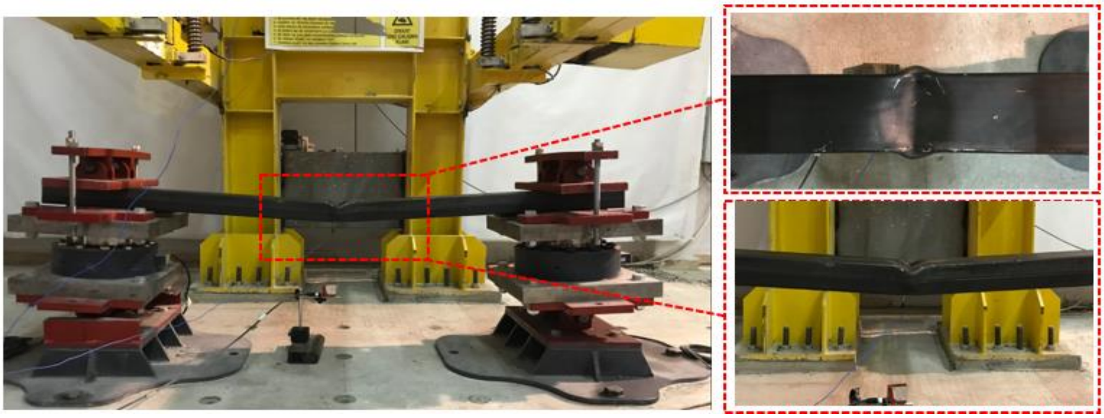
### 4.2. Damage status

As a result of the experimental study, two types of damage occurred in the steel beam element, namely local plastic deformation and consequent out-of-plane denting formation. In the case of this damage, crushing occurred on the surface of the beam element, which was hit by the impactor, and this crushing increased with each repetitive impact. With the local plastic crushing, out of plane denting was formed on the rectangular hollow steel beam. Figure 4 shows the damage conditions that occurred in the central parts of the beam for all test elements. Plastic deformation due to repetitive impacts has increased in each series. The second observed damage status was the damage condition called global deformation. The occurrence of both elastic and plastic deformations was observed in global deformation. When the displacement-time graphs in Fig. 4 were examined, the maximum displacement have occurred in the beam right after impact force hit the specimen, but when the load was removed, some of the displacement was restored. The remaining displacement is the amount of permanent and plastic deformation. This situation (Global plastic deformation) was observed in the RIB and RIC series but was not observed in the RIA series. From this, it can be inferred that the larger the impact force the bigger will be the global displacement value.

### 4.3. Finite element results

Three finite element models were developed and each model had three variations of repeated impact loading, therefore, a total of 9 dynamic explicit impact analyses have been conducted to numerically investigate the effects of repeated impact loading on rectangular hollow steel beam. In the first stage of the numerical analysis, all three finite element models were verified using the experimental data. As it can be seen in Fig. 5, predicted and observed plastic deformation and out of plane plastic denting are closely similar to each other. Additionally, the repeated impact loading analysis was conducted on the deformed shape of the finite element model. All results obtained from numerical studies are presented in Table 3. The smallest difference between the finite element and the experimental is seen in RIA-1 (first hit of the impactor at 400 mm) and the biggest difference was observed in the RIC-3 series (third hit of impactor at 1200 mm) on the steel beam which was calculated as 7.06%. These values contain sufficient convergence for the finite element verification accepted in the literature. Since the impact loading is a type of dynamic load, especially the verification on the deformed shape of the element is too difficult. Thus, the verification of the numerical models is acceptable and other results of the numeric models such as Von Mieses Stress distribution and out of plane plastic denting can be evaluated for more investigation of the rectangular hollow steel beam under repeated impact loading. In Fig. 6 the damage prediction with Equivalent Plastic strain (PEEQ) and observed damaged during the experimental studies have been illustrated. As it shown in the Fig. 6 the similarity of the occurred damage shows the validation of the numerical models.

The Von Misses stress distribution obtained from the RIA, RIB and RIC series with the help of the finite element models are shown in Fig. 7 and the stress values are given in Table 3. There is a direct proportionality between stress, displacement and damage. As it can be seen in Table 3, the minimum stress value of 242 MPa occurred in the RIA-1 sample with the least displacement. On the other hand, in the RIC-3 sample with the largest displacement, the stress value was recorded as 281 MPa. In all the series, the plastic deformation and damage that occurs in the element as a result of the first impact occurs in the region where the hammer touches the sample, and when Fig. 7 is examined, it is seen that the stress value is concentrated in the central region of the beam. Stress distribution did not occur in the non-damaged regions close to the support in all of the test specimens. In addition, the increase in the hammer height value caused an increase in the damage value of the element. The damage to the element as a result of the increase in the hammer height was due to the increase in the stress value. As a matter of fact, there was a 4% increase in the stress value after three strokes of the hammer drop from a height of 400 mm in the RIA series, 6% from a height of 800 mm in the RIB series, and 9% at the end of the third stroke from a height of 1200 mm in the RIC series.



(a)

RIA-1 RIA-2 RIA-3

(b)

RIB-1 RIB-2 RIB-3

(c)

RIC-1 RIC-2 RIC-3

(d)

Fig. 5. The experimental damage occasion in (a) RIC-3 test, damage condition under repeated impact loading for test series (b) RIA, (c) RIB and (d) RIC

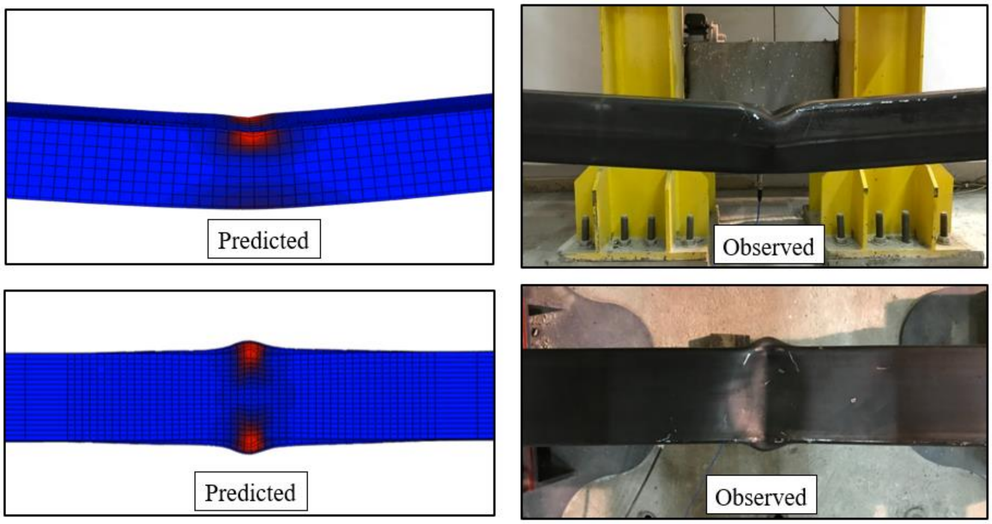



Fig. 6. Predicted via finite element model and experimental damage observation of RIC-3

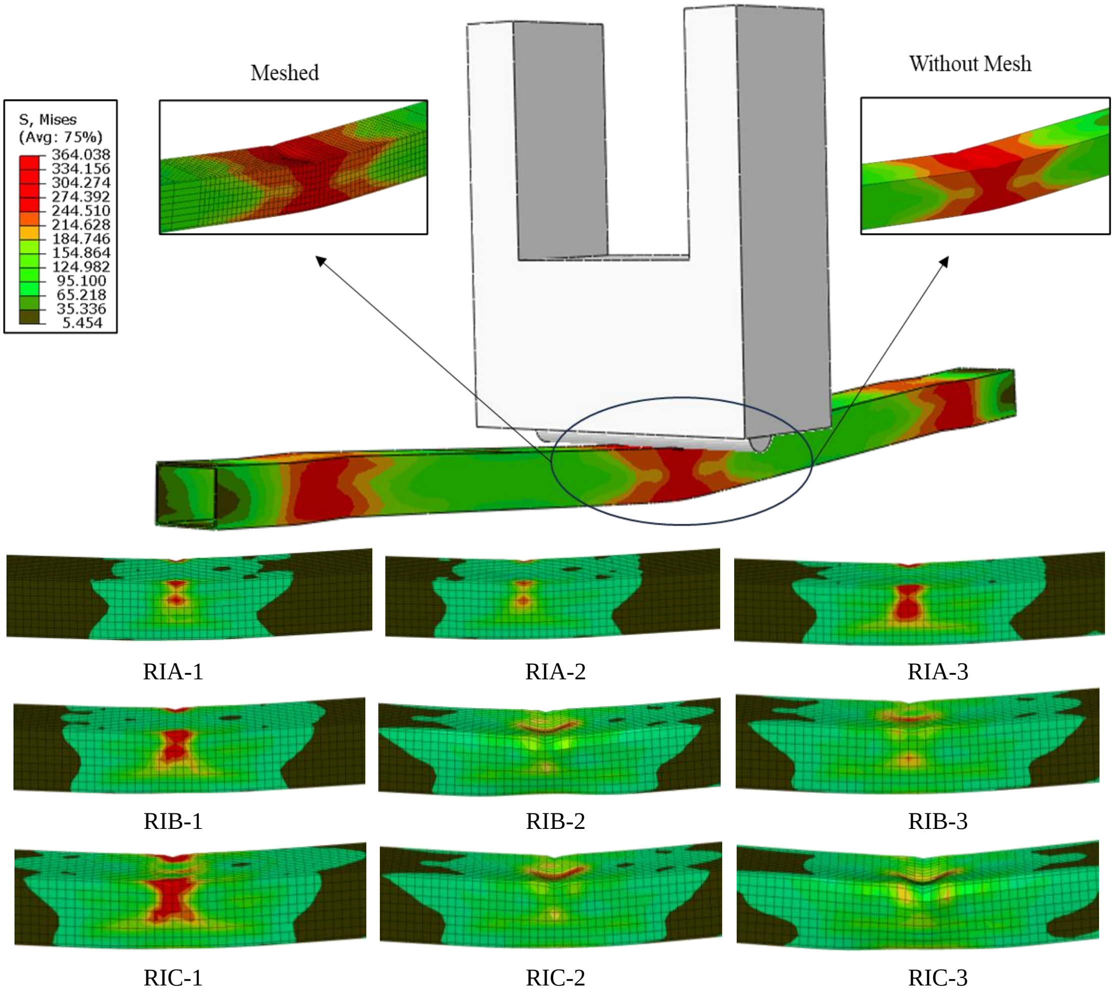



Fig. 7. Von Mises stress distribution under repeated impact loading for all finite element models

Table 3. Comparison of experimental results with FE results

| Analysis Series | Specimen label | Drop height of weight (mm) | Impactor weight (kN) | Steel beam section (mm) | Max. Displacement (mm) | | | Residual displacement (mm) | | | Reaction forces (kN) | | Von Mises stress distribution | Out of plane Denting (Δb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Exp | Fem | Dif (%) | Exp | Fem | Dif (%) | Exp | Fem | Fem | Fem |
| A | RIA-1 | 400 | 75 | 120×80×3 | 8.65 | 8.61 | 0.46 | 1.37 | 3.6 | 6.94 | 61.79 | 51.9 | 242.1 | 3.15 |
| | RIA-2 | 400 | 75 | 120×80×3 | 11.93 | 12.06 | 1.08 | 2.62 | 6.89 | 262 | 61.07 | 52.03 | 247.6 | 5.20 |
| | RIA-3 | 400 | 75 | 120×80×3 | 15.12 | 15.50 | 2.45 | 3.82 | 10.02 | 262 | 58.85 | 47.7 | 252 | 8.72 |
| B | RIB-1 | 800 | 75 | 120×80×3 | 13.60 | 13.40 | 1.49 | 2.73 | 9.01 | 330 | 65.56 | 63.08 | 250.9 | 6.32 |
| | RIB-2 | 800 | 75 | 120×80×3 | 19.78 | 20.30 | 2.56 | 6.02 | 14.07 | 234 | 64.55 | 67.8 | 260.1 | 10.27 |
| | RIB-3 | 800 | 75 | 120×80×3 | 26.76 | 27.80 | 3.74 | 12.17 | 21.92 | 180 | 61.33 | 53.04 | 267.2 | 15.68 |
| C | RIC-1 | 1200 | 75 | 120×80×3 | 22.60 | 21.40 | 5.60 | 8.95 | 15.92 | 63.78 | 79.02 | 50.15 | 256.5 | 10.78 |
| | RIC-2 | 1200 | 75 | 120×80×3 | 37.90 | 40.20 | 5.72 | 21.46 | 29.91 | 28.25 | 69.90 | 77.08 | 268.7 | 14.25 |
| | RIC-3 | 1200 | 75 | 120×80×3 | 56.60 | 60.90 | 7.06 | 42.84 | 45.00 | 4.8 | 55.12 | 54.93 | 281.3 | 21.55 |

**Exp:** Experimental results; **Fem:** Finite element models results; **Dif:** Differences; **$\Delta_d$:** Out of plane denting

During impact loading, the energy absorbed by the section causes plastic deformation in the rectangular hollow steel beam, which occurs in a local area and is expressed as plastic denting. The denting formed perpendicular to the beam's axis, in the direction of the applied force, is seen at the midpoint of the beam in the region where the displacement and stress distribution are most intense (Fig 8). Therefore, the increase in hammer height causes an increase in the displacement value of the element and an increase in the denting value. When the hammer height was doubled between the RIA and RIB series, there was an increase of 55% in the displacement value and an increase of 80% in the denting value. In the RIB and RIC series, when the height was increased by 1.5 times, the displacement value increased by 60%, while the denting value increased by 37%. It has been observed that the denting value formed under the impact load is a parameter for determining the damage value of the element (Fig. 9).

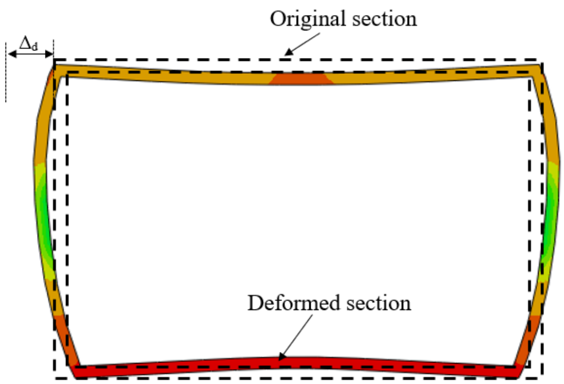



Fig. 8. Simulation the defamation shape and out of plane denting detail of RIC-3 specimen under repeated impact loading

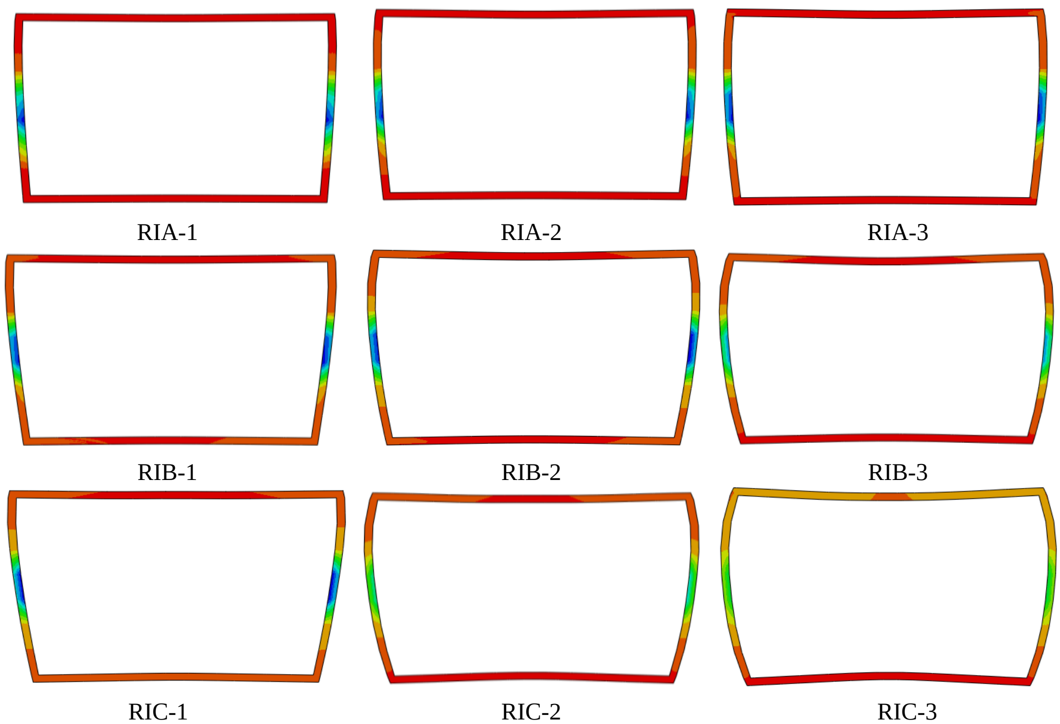



Fig. 9. Simulation the defamation shape and out of plane denting detail of RIC-3 specimen under repeated impact loading

The displacement-time and reaction force-time histories obtained from numerical studies for all series are given in Fig. 10. Similar to experimental results, the increase in the hammer height value in the element in series RIC caused an increase in the displacement value of the element and an increase in the margin of error. In series RIA, RIB and RIC, The increase in the margin of error in the second and third hits was due to the fact that the part defined as the initial condition in the finite element modeling is taken from the previous impact. The error in the first hit is collected in the second hit and the error in the second hit is collected in the third hit. However, in the experimental study, the devices in the experimental setup may flex or the small movements may come back again. In the finite element model, such situations are not allowed. Therefore, the difference between maximum displacement and reaction forces of numerical and experimental results increased by repetition of impact loading.

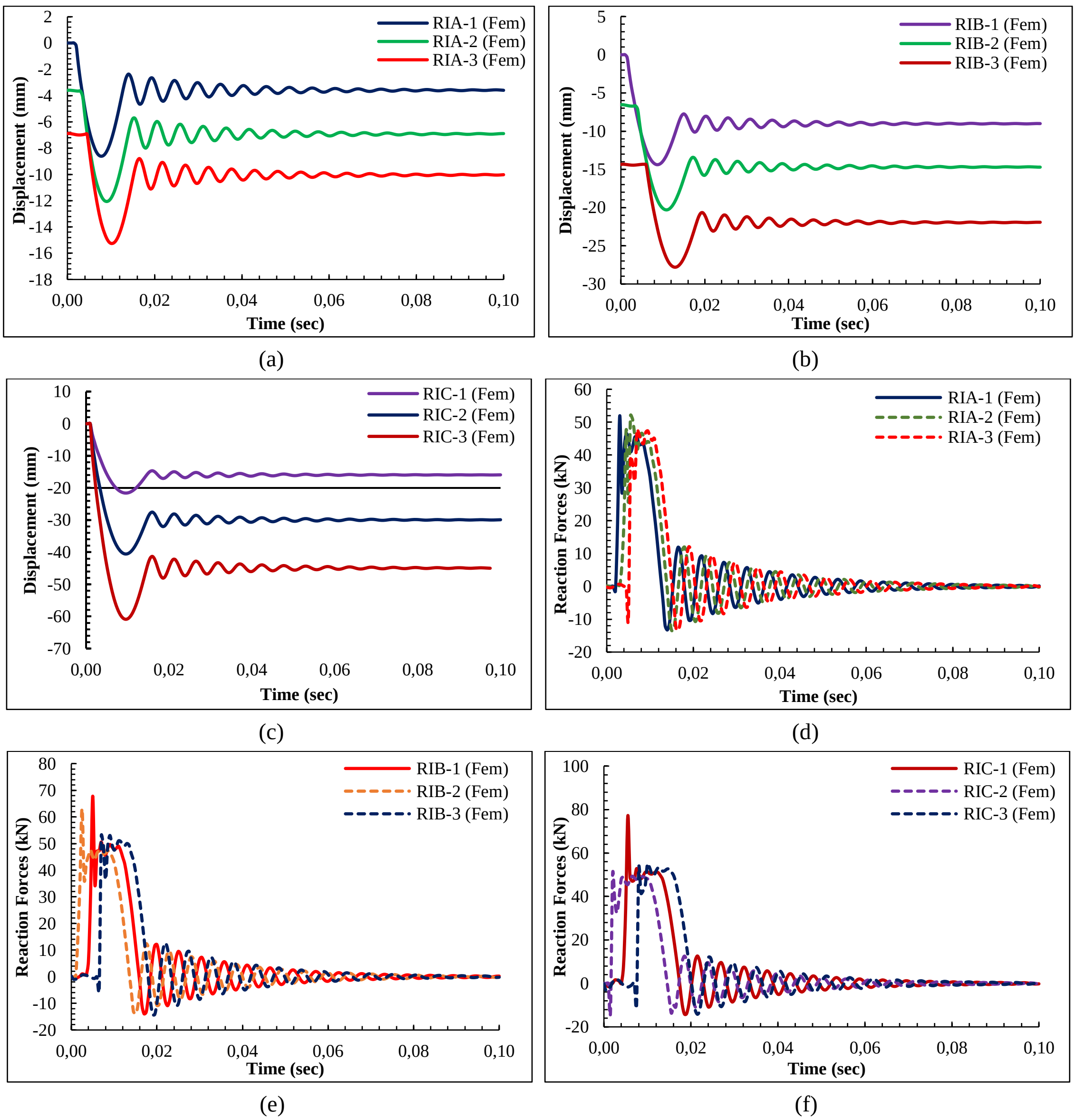



Fig. 10. Numerical results of displacement-time histories of test series (a) RIA, (b) RIB, (c) RIC, and the reaction force-time histories for test series (d) RIA under 400 mm, (e) RIB under 800 mm and (f) RIC under 1200 mm of height of impactor

## 5. Conclusions

In this study, the effects of repeated impact loading on rectangular hollow steel beam were investigated experimentally and numerically. For this purpose, three specimens were prepared with the length of 2000 mm and cross-sectional dimensions of 120×80×3 mm in the Sakarya University Laboratory. Three specimens were tested under three different heights of 400 mm, 800 mm and 1200 mm, respectively. In addition, to obtain the effects of repetitive impact force, each specimen was tested three times under repeated impact loading. As a result, displacement, reaction force and damage status were obtained from the experimental studies. In the second part of the study, numerical models for the purpose of finite element analysis of the specimen were developed and verified by experimental data. In addition to displacement, reaction force and damage status which were obtained experimentally, the stress distributions and out of plane plastic denting were obtained from the finite element models. The following conclusions can be drawn from the study:

- When the height value is increased twice the initial height, in test series RIA and RIB, the displacement value increased by 57% in the first hit, 68% in the second hit and 79 % in the third hit. Thus, it seems that the increase in the displacement value due to the increase in the damage of subsequent hits is not linear, but rather logarithmic,
- In Series RIA, RIB and RIC, the displacement value increased between %38-67% at the second hit, and 26-49% at the third hit respectively. Therefore, the plastic deformation that occurs in the element as a result of the third impact is not as much as the second hit. This means that by increasing the plastic deformation of the section, a considerable amount of the impact energy absorbed by the section and all of it is not transferred to the outside of the section.
- When the reaction forces-time graphs are examined in the RIA series, the maximum reaction force obtained on the second hit was 1.16% less compared to the first hit, while a 5.10%-26.81% lower value was obtained in the third hit compared to the second hit. Thus, with the increase in the plastic deformation and displacement occurring in an element subjected to repeated impact loading, a decrement has occurred in the reaction force transferred to the supports.
- Two types of damage occurred in the steel beam element, namely local plastic deformation and consequent out-of-plane denting formation. With the local plastic crushing, out of plane denting was formed on the rectangular hollow steel beam. Plastic deformation due to repeated impact has increased in each series.
- The second observed damage status was the global deformation. Both, elastic and plastic deformations were observed in global deformation. The maximum displacement has occurred in the beam right after impact force hit the specimen, but when the load was removed, some of the displacement was restored. The remaining displacement is the amount of permanent and plastic deformation. Global plastic deformation was observed in the RIB and RIC series but was not observed in the RIA series. From this, it can be inferred that the larger the impact force the bigger the global displacement value will be.
- Three finite element models were developed for numerical analysis of repeated impact loading. The smallest difference between the finite element and the experimental was seen in RIA-1 (first hit of the impactor at 400 mm) and the biggest difference was observed in the RIC-3 series (third hit of impactor at 1200 mm) on the steel beam which was calculated as 7.06%. Thus, the verification of the numerical models is acceptable and the other results of the numeric models such as Von Mieses Stress distribution and out of plane denting can be evaluated for further investigation of the rectangular hollow steel beam under repeated impact loading.
- The increase in the hammer height value caused an increase in the damage value of the element. As a matter of fact, there was a 4% increase in the stress value after three strokes of the hammer drop from a height of 400 mm in the RIA series, 6% from a height of 800mm in the RIB series, and 9% at the end of the third stroke from a height of 1200 mm in the RIC series. Thus, the increase in the hammer height

value and increase in the repetition caused an increase in the Von Misses stress distribution under impact loading.

- When the hammer height was doubled between the RIA and RIB series, there was an increase of 55% in the displacement value and an increase of 80% in the out of plane denting value. In the RIB and RIC series, when the height is increased by 1.5 times, the displacement value increased by 60%, while the out of plane denting value increased by 37%. It has been observed that the denting value formed under the impact loading is a parameter for determining the damage value of the element.

Finally, the repeated impact loading had a very significant effect on the rectangular hollow steel beam and as the number of impacts increased, the element lost its strength due to the damage. In order to better understand the effects of repetitive impact loading, it is strongly recommended to investigate the behavior of beam elements with other geometric sections such as IPE, HEA and UPN under repeated impact loading.

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## Data availability statement

No new data were created or analyzed in this study.

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