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Transverse Impact on Hollow and Concrete Filled Steel Tubular Members: An overview

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ABSTRACT

This paper clarifies a review of research progress in the transverse impact process on hollow and Concrete Filled Steel Tubular (CFST) members and their dynamic response under impact loading. This review emphases analytical, numerical and experimental studies recently performed by many researchers. It clarifies the influence of some fundamental parameters on the impact performance such as; axial load level, impact energy, steel ratio, constraining (confining factor), steel tube thickness, diameter-to-thickness ratio of the steel tube. In addition to exploring the effect of concrete and steel material properties and specimen boundary conditions. It also goes through the effect of using Carbon Fiber Reinforced Polymer (CFRP) jackets. The review explained with detailed discussions the stages of impact process, impact energy, dissipated energy, failure modes, life-cycle performance of Concrete Filled Steel Tubular (CFST) members subjected to impact load. The influence of strain rates on the performances of concrete and steel are discussed as well.

1. Introduction

In construction projects such as highway bridge columns, electricity transmission towers, high-rise buildings and bridge piers, the Concrete Filled Steel Tube (CFST) members have been commonly used due to the excellent resistance to blasting, seismic loading and impact, as well as better fire resistance, better ductility and shorter construction times than concrete members. In addition, core concrete prevents or reduces the risk of local steel tube buckling and also the steel tube provides excellent confinement for core concrete enhancing plastic deformation capability and bearing capacity. Whereas the presence of the CFST members in these projects may expose them to collision of naval vessels and vehicles, (As illustrated in Fig.1.) resulting in severe damage. This can harm the whole structure that urged researchers to investigate the impact performance and behavior under transverse impact. This was achieved through experimental study, nonlinear finite element analysis (FEA) performed using software packages as ABAQUS, LS-DYNA, ANSYS. The simplified analytical model depended on the dynamic plastic moment and plastic hinges as a failure mechanism.

In order to obtain the relationships of force-displacement and energy-absorption, Bambach et al, [1] carried out analytical and experimental studies of low velocity and high mass transverse impacts on the hollow and concrete filled steel tubular members.

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They observed that by the concrete filling, the absorbed energy decreased and the transverse failure deflection decreased which especially became more evident as the section slenderness increased. Huo et al, [2] experimentally investigated Concrete–Filled Steel Tubular members under impact loading at high temperatures up to 400 ^{o} C in order to investigate the impact performance. They indicated that (CFST) exhibited excellent resistance to impact and excellent resistance to deformation under high temperature. Remennikov et al, [3] performed numerical and experimental analysis of the impact performance of mild steel tubes and stainless steel with Rigid Polyurethane Foam (RPF) and concrete infilling under transverse impact load.

They analyzed the impact behavior of hollow square stainless steel and mild steel and the effect of (RPF) and concrete infilling on the impact behavior under transverse loading. They demonstrated that the energy absorption capacity and the impact resistance of the concrete – filled tubes were the largest, followed by Rigid Polyurethane Foam (RPF) – filled tubes and then the hollow tubes. They also clarified that the stainless steel tubes had greater resistance to impact and capacity of energy absorption than mild steel tubes for hollow, concrete – filled and (RPF) – filled. Qu et al, [4] conducted theoretical, empirical and experimental investigation of circular concrete filled steel tubes under impact loading. They indicated that the residual displacement increased with increasing of the initial impact energy.

Bambach [5] investigated the behavior of stainless steel tubes and thin-walled steel filled with hollow and concrete infilling against transverse impact. The principal parameter was studied is member's ability to absorb transverse impact energy. He found that specimens with no end rotational restraint showed less absorbed energy capacity than specimens with a full-end rotational restraint by (18%). He also clarified that the stainless steel specimen absorbed energy on average 1.8 times more than the energy absorbed by steel specimen. Deng et al, [6] experimentally tested twelve specimens of concrete Filled Circular Steel Tubes (CFSTs), Post-Tensioned Concrete Filled Circular Steel Tubes (PTCFSTs) and Fiber–Reinforced Concrete – Filled Circular Steel Tubes (FRCFSTs) under high strain rate impact load. They analyzed the impact performance and compared the behavior against impact load. They explained that Posttensioned Concrete Filled Circular Steel Tubes (PTCFSTs) had the highest impact resistance then reinforced concrete – filled circular steel tubes (FRCFSTs) then (CFSTs). They also clarified that under the same initial collision energy, (PTCFSTs) showed the least maximum dynamic deflection then (FRCFSTs) then (CFSTs). Wang et al, [7] studied the impact performance of Concrete-Filled Steel Tubular (CFST) under collision loading numerically and experimentally. They studied key parameters such as the constraining factor, the impact energy and the level of axial load. They mentioned that the collision force, residual deflection and duration of impact force increased with increasing the initial impact energy. They also reported that the critical fracture energy increased and specimens behave more ductile with an increase in the confining factor. Yousuf et al, [8] numerically and experimentally examined the performance of hollow and concrete filled stainless steel tubes under static and transverse impact loads. They analyzed the deformed shapes, column strength and load-deflection curve as well as they compared between the numerical and experimental results. They clarified that Hollow and Concrete-Filled Stainless Steel has better strength and ductility compared with steel. They also demonstrated that the Concrete-Filled Stainless Steel showed 45% higher impact load capacity than that of the hollow sections. Al-Husainy et al, [9] tested three dimensional, nonlinear finite element analysis of (CFST) columns under impact load. This research involved the effects of the confinement, the tube length, the properties of the materials after cracking and the configurations of the projectiles. They indicated that the axial load affected the static and collision strength, the collision force and the lateral deflection of stainless steel tubes. Han et al, [10] tested twelve specimens of hollow steel tubes and circular high-strength (CFST) under impact loads. They investigated the performance and the flexural capacity of members under impact loads. In addition this research investigated the effects of key parameters such as; mass of drop hammer, boundary conditions, impact height and steel ratio. They demonstrated that with the increasing in the steel ratio, the mid-span displacement and the impact duration decreased significantly. They also concluded that the inner concrete contributed to more ductile deformation modes for (CFST) than hollow steel tubes. As well as, it eliminated the incidence of local buckling in the steel tube. They also reported that boundary conditions had an effect on CFST specimen failure modes. Wang et al, [11] investigated numerically and experimentally the impact behavior of sixteen Ultra-Light Cement Composite (ULCC) Filled Pipe – in – Pipe Composite Tubes and six hollow steel pipes under transverse impact loading. They indicated that the strong confinement was supplied by steel pipes in Ultra-Lightweight Cement Composite (ULCC) Filled Pipe – in – Pipe Composite tubes, increased impact resistance and decreased the brittleness of (ULCC). They also explained that increasing of the inner pipe thickness marginally influenced the local indentation compared to increasing of the outer pipe thickness.

Yang et al, [12] numerically and experimentally tested twelve specimens of Recycled Aggregate Concrete (RAC) filled steel tubes under transverse impact load. They investigated the impact performance. This research concentrated on main parameters such as; (1) Recycled coarse aggregate replacement ratio (r). (2) Height of drop weight (h). (3) Axial compressive load level (n). (4) Failure modes. They demonstrated that during impact testing, axial compressive load existence can improve the plastic failure capability of (RAC) concrete core. They also explained that (RACFST) specimens had better deformation – resistance capability as normal (CFST) specimens. Alam et al, [13] performed Finite element investigation on Carbon Fiber Reinforced Polymer (CFRP) strengthening (CFST) column under transverse impact loading. They indicated that strengthening concrete by (CFRP) sheets improved its impact resistance.

Eighty-four specimens were experimentally investigated under transverse impact loading by Shakir et al, [14]. Specimens were of hollow steel tubes and recycled aggregate or normal aggregate concrete filled steel tubes (RACFST or NACFST) without and with (CFRP) jackets. This research analyzed the effects of key parameters on the impact behavior of columns such as; length of the tube, (CFRP) confinement and shape or diameter of the impactor and the concrete type. They clarified that as the tube length of CFST increased, the stiffness decreased so the impact force and local displacement (indentation) decreased. Whereas the global displacement increased. They also demonstrated that the (NACFST) columns had higher impact resistance than (RACFST) columns. They demonstrated that with the usage of (CFRP) jackets, (RACFST) columns displayed equal impact resistance to (NACFST) columns. Li et al, [15] performed experimental and numerical impact analyses on Recycled Aggregate Concrete – Filled Steel Tube (RACFST) with (RAC) replacement ratio (0%, 50% and 100%) at various temperature (20 c, 200 c, 500 c and 700 c). They analyzed the influence of principal parameters on the impact deformation resistance and the impact performance of (RACFST). Parameters were steel strength, (RAC) strength, steel ratio, (RAC) replacement ratio and different exposure temperature. They demonstrated that rising the steel ratio was becoming increasingly effective in enhancing impact resistance and reducing impact deformation (RACFST). They also demonstrated that rising the steel ratio was becoming increasingly effective in enhancing impact resistance and reducing impact deformation (RACFST). They also clarified that the contribution of steel tube to improve the impact resistance at elevated temperature is higher than the contribution of (RAC) core. They also indicated that with the increase of (RAC) content, the resistance to high temperature and the impact resistance of (RACFST) decreased. Hu et al, [16] carried out numerical investigation on the impact behavior of Circular Concrete – Encased Concrete – Filled Steel Tube (CFST) columns under low velocity transverse impact. This research explained the effect of key parameters on the deflection of mid-span and impact resistance. Key parameters were (1) Geometric parameters (diameter of steel tube - tube thickness - steel ratio). (2) Material parameters (yield strength of steel - strength of outer and core concrete). (3) Loading parameters (axial load levels - initial velocity of hammer - mass). They proved that the steel ratio affected the flexural capacity and the mid-span deflection of Circular Concrete – Encased Concrete – Filled Steel Tube (CFST) columns. They also demonstrated that the strength of core concrete had less effect on the flexural capacity and the mid-span deflection compared to the steel's yield strength, the steel ratio and larger sectional diameter. They also indicated that Concrete – Encased Concrete – Filled Steel Tube columns showed better impact resistance, better reparability and lower residual deflection than (CFST) and (RC) columns.

The impact behavior of 20 specimens of Concrete-Encased-Concrete-Filled Steel Tubular (CFST) box under a drop hammer was investigated experimentally and numerically by Hou et al, [17]. They explained the effects of the test parameters on the residual deflection of mid-span, the peak value of the impact force and the impact duration. Parameters were (1) The boundary condition. (2) The axial load level. (3) The impact energy. (4) Thickness of steel tube. They clarified that the impact resistance of specimens could be improved at the low axial load level. Whereas as a result of the section's load-moment interaction curve, the high-level axial load did not become a beneficial factor for the impact resistance. They also reported that the impact duration was shorter and the residual deflection was smaller with the axial load applied than specimens without axial load. They also clarified that rising of the thickness of the steel tube provided minimal increase in impact resistance and decreased the lateral deflection.

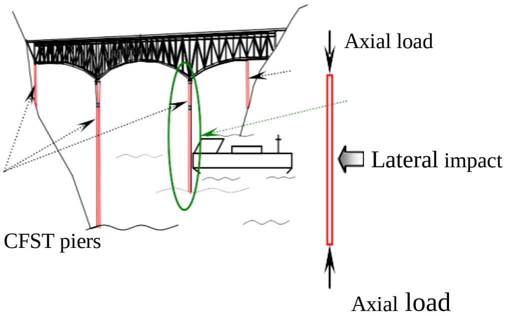

Fig. 1. A graphical view of the collision between the ship and the bridge. (Wang et al, [7])

2. Vital Definitions

2.1. Low-velocity impact

Low-velocity impact can be treated as quasi-static and it can dissimilar from 1 to 10 m/s depending on the stiffness and properties of specimen in addition to the stiffness and mass of impactor, as it was defined by Sjoblom et al, [18] and Shivakumar et al, [19]. As well as, in low-velocity impact, the period of contact is long enough for specimen to react to the impact and more energy is elastically absorbed.

2.2. High-velocity impact

In high-velocity collision, the stress waves propagate through the specimen, in which the specimen does not have enough time to respond, causing much localized damage. As well as in high-velocity impact, the possibility of neglecting the boundary condition effects as the impact effect is over before the stress waves hit the edge of the specimen, as it was defined by Sjoblom et al, [18] and Shivakumar et al, [19].

2.3. Strain rate effect

During impact loading, the performances of concrete and steel structures are completely dissimilar from those when during quasi-static load. At high strain rates within 10 to 1000 s-1 or even higher, the tensile and compressive strengths for both of the concrete and steel can significantly increase by 100% and even more [20-23].

Under different strain rates, the yield strength of steel was determinate with Cowper-symonds, as illustrated in Eq. (1):

$$\mathbf{F_y^d/F_{y\,=\,1\,+\,(\varepsilon_{d\,/\,D})}^{1/p}} \qquad (1)$$

Where F_y is the steel's static yield strength, F_y^d is the steel's dynamic yield strength under strain rate **ε** and the values of p and D were set as 3.91 and 6844 s^{-1}, respectively (Abramowicz and Jones [24]).

Under impact loading, the concrete's dynamic compressive strength is stated in the CEB-FIP model code (Comite Euro-International du Beton [25]) as illustrated in Eq. (2):

$$\mathbf{F_c^d/F_c} \begin{cases} = (\varepsilon_{d/}\varepsilon_s)^{1.026\alpha} & \text{for } (\varepsilon_d \le 30\ s^{-1}) \\ = \gamma_s\ (\varepsilon_{d/}\varepsilon_s)^{1/3} & \text{for } (\varepsilon_d > 30\ s^{-1}) \end{cases} \qquad (2)$$

Where $\mathbf{F_c = F_{ck} + 8}$ **(MPa)**, $\mathbf{F_{ck}}$ is the concrete's characteristic static compressive strength at the static strain rate **($\varepsilon_s = 30 \times 10^{-6}\ s^{-1}$)**, $\mathbf{F_c^d}$ is the concrete's dynamic compressive strength under strain rate $\boldsymbol{\varepsilon_d}$, **($\log \gamma_s = 6.156\ \alpha - 2$), $\alpha = (5 + 9\ F_c/F_{co})^{-1}$**, **$F_{co} = 10$ (MPa)**.

Under impact load, the concrete's dynamic tensile strength is also stated in the CEB-FIP model code (Comite Euro-International du Beton, [25]) as illustrated in Eq. (3):

$$\mathbf{F_t^d/\ Ft} \begin{cases} = (\varepsilon_{d/}\varepsilon_s)^{\delta} & \text{for } (\varepsilon_d \le 1\ s^{-1}) \\ = \beta\ (\varepsilon_{d/}\varepsilon_s)^{1/3} & \text{for } (\varepsilon_d > 1\ s^{-1}) \end{cases} \qquad \mathbf{(3)}$$

Where $\mathbf{F_t}$ is the characteristic static tensile strength of concrete at the static strain rate **($\varepsilon_s = 1 \times 10^{-6}\ s^{-1}$)**, $\mathbf{F_t^d}$ is the dynamic tensile strength of concrete under strain rate **($\varepsilon_d = 10^{-6}$ to $160\ s^{-1}$), ($\log \beta = 6\delta - 2$), $\delta = (1 + 8\ F_c/F_{co})^{-1}$, $F_{co} = 10$ (MPa)**.

Richardson [26] Concluded that under low-velocity collision, the strain rate effect for steel and concrete is neglected.

2.4. Impact force

It was found that the impact process of specimens consists of three stages as it was clarified by Deng et al, [6]. The time history of impact force can be separated into three stages; (1) in a short time, the impact force reached rapidly to its peak value at contact with the specimen. Then it decreased as a consequence of the deflection of the specimen. The secondary peak value occurred when the impactor recontacted with the specimen. (2) The time history of impact force revealed a plateau when the impactor and specimen came down together. However there was no plateau stage when the specimen collapsed in rupture. (3) As shear waves move faster than bending waves, the time required to travel the shear wave from mid span to the support occurs time lag in the time history of reaction force in according to the time history of impact force. Wang et al, [7] clarified that the time history of impact force could be separated into three stages; (1) Peak stage (in short time the impact force reach to its peak value). (2) Platform stage (the most impact energy is depleted and the impact force reclaims a steady value for long time). (3) Unloading stage (the impact force showed rapidly decreasing to zero). Wang et al, [11] demonstrated that the time history of impact force could divide into three stages; (1) vibration stage (at short time, impact force sharply increases to its peak value). (2) Stable stage (specimen shows maximum global displacement). (3) Unloading stage (indenter starts to separate from specimen and the impact force decreases to zero).

The research performed by Yang et al, [12] clarified that the time history of impact force can be separated into three stages (as seen in fig.2.); (1) oscillation stage. (2) Stabilization stage. (3) Attenuation stage. The change was observed in three stages and their duration as variations of Recycled Coarse Aggregate replacement ratio (r), Axial compressive load ratio (n) and Height of the drop-weight (h). Hu et al, [16] described the time history curve of the sectional moment and impact force into three stages; (1) initial impact stage (the sectional moment small drops and the impact force decreases sharply after reaching their maximum values. In addition, the deflection of member insignificantly develops). (2) Plastic deforming stage (the sectional moment and impact force develop with a constant value and the impact energy is depleted by the plastic deformation as well as, the deflection of mid-span develops to the maximum value). (3) Decreasing stage (the sectional moment decreases, the impact force also decreases to zero. As a result of the occurrence of the recovered elastic deformation, the deflection of mid-span little decreases). Hou et al, [17] concluded that the time history of impact force can be separated into three stages: (1) peak stage. (2) Plateau stage. (3) Descending stage. It was observed that as the local deformation of the specimen, the peak stage of impact force has short duration. In addition, as largely dissipated impact energy during an occurrence of the specimen's plastic deformation, the plateau stage has relatively long duration.

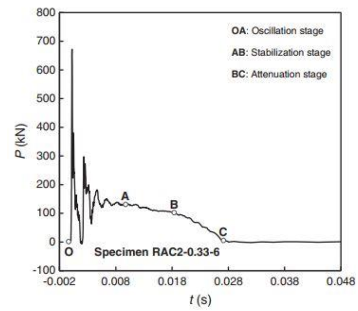

Fig. 2. Typical time history of impact loads.(Yang et al, [12])

2.5. Impact energy and dissipated energy

2.5.1. Impact energy

Initial impact energy is defined by Deng et al, [6] as the gravitational potential energy of impactor **(E_o = mgh)** and also it is defined by Wang et al, [7] as kinetic energy of impactor **($E_o = 0.5mv^2$)**, Where**:** (h: Impact height, m: Drop hammer's mass, v: Velocity of drop hammer and g: Gravity Acceleration).

2.5.2. Dissipated energy

Remennikov et al, [3] explained that The area under the impact force – displacement curve represents the external work performed by the impact force which is almost equal to the initial impact energy as a result, a little energy is lost from impact. They also explained that the impact energy is equal to the strain energy consumed by plastic hinge (absorbed energy) plus the strain energy returned by elastic rebound of a specimen (recovered energy), (as illustrated in fig.3.).

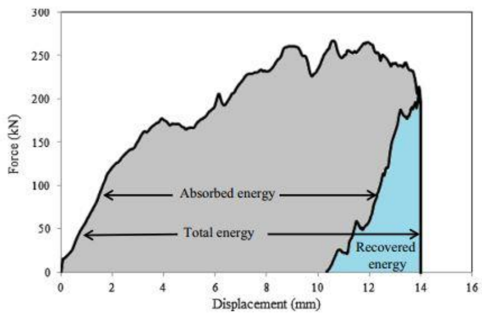

Fig. 3. The impact force – displacement curve. (Remennikov et al, [3])

3. Fundamental Parameters effect on the impact performance of CFST

3.1. axial load level

Wang et al, [7] explained that the critical fracture energy, collision resistance, collision force increased and the collision force duration decreased at low axial load level. Whereas the impact resistance, critical fracture energy, impact force and the impact force's period decreased at high axial load level. Al-Husainy et al, [9] indicated that the axial load affected the static and collision strength, the collision force and the lateral deflection of stainless steel tubes. Yang et al, [12] demonstrated that during impact testing, axial compressive load existence can improve the plastic failure capability of (RAC) concrete core. In addition, it can restrict the progress of tensile strain in the tube in (RACFST) specimens. Hu et al, [16] explained that as low axial compressive load level and the composite action between concrete and steel tube, concrete – encased concrete – filled steel tube column showed high impact resistance. While at high axial load level, the impact resistance significantly dropped. Hou et al, [17] clarified that the impact resistance of specimens could be improved at the low axial load level. Whereas as a result of the section's load-moment interaction curve, the high-level axial load did not become a beneficial factor for the impact resistance. They also reported that the impact duration was shorter and the residual deflection was smaller with the axial load applied than specimens without axial load.

Where (The axial load level (n)):

$$(n = N_o / Nu)$$

(No) is the axial load applied on the specimen; (Nu) is the axial compressive capacity of the CFST specimen.

3.2. Impact energy

Qu et al, [4] indicated that the residual displacement increased with increasing of the initial impact energy. Wang et al, [7] mentioned that the collision force, residual deflection and duration of impact force increased with increasing the initial impact energy. Han et al, [10] reported that the mid-span displacement as well as the peak value, plateau value and the duration of the impact force increased with increasing of impact energy. Shakir et al, [14] indicated that impact resistance and the energy dissipation increased with increasing the kinetic impact energy. Hu et al, [16] explained that the strain rate of concrete and steel increased with increasing the impact velocity so the dynamic flexural capacity increased. Whereas the hammer mass had little influence on the dynamic flexural capacity. Hou et al, [17] concluded that with increasing the impact energy, the impact duration, the peak value of impact force and the mid-span residual deflection increased.

3.3. Steel ratio, constraining factor

Constraining factor (also known as confining factor) can be determined by: ($\xi = A_s f_y / A_c f_{ck}$). Where: (As: steel tube's area, Ac: core concrete's area, fy: steel's yield strength, fck: concrete's characteristic compressive strength). Wang et al, [7] reported that the critical fracture energy increased and specimens behave more ductile with an increase in the confining factor. Han et al, [10] demonstrated that with the increasing in the steel ratio, the mid-span displacement and the impact duration decreased significantly. While the peak value and the plateau value of the impact force increased, indicating that the impact resistance of the member increased. Wang et al, [11] indicated that the strong confinement was supplied by steel pipes in Ultra-Lightweight Cement Composite (ULCC) Filled Pipe – in – Pipe Composite tubes, increased impact resistance and decreased the brittleness of (ULCC). Li et al, [15] demonstrated that rising the steel ratio was becoming increasingly effective in enhancing impact resistance and reducing impact deformation (RACFST). Hu et al, [16] proved that the steel ratio affected the flexural capacity and the mid-span deflection of Circular Concrete – Encased Concrete – Filled Steel Tube (CFST) columns.

3.4. Diameter to thickness ratio of steel tube

Wang et al, [11] demonstrated that the impact resistance, impact force, energy absorption capacity, local indentation resistance and global deformation resistance increased with increasing in the outer pipe's thickness and cement composite for Ultra-lightweight Cement Composite (ULCC) Filled Pipe – in – Pipe Composite tubes. They also explained that increasing of the inner pipe thickness marginally influenced the local indentation compared to increasing of the outer pipe thickness. Hou et al, [17] clarified that rising of the thickness of the steel tube provided minimal increase in impact resistance and decreased the lateral deflection.

3.5. Length of Steel tube

Shakir et al, [14] clarified that as the tube length of CFST increased, the stiffness decreased so the impact force and local displacement (indentation) decreased. Whereas the global displacement increased.

3.6. Impactor configurations

Shakir et al, [14] clarified that as increasing the diameter or size of impactor, the contact area between the impactor and specimen increased. As well as, the contact impact force, the local displacement (indentation) and the collision resistance increased while the global displacement decreased.

3.7. Concrete strength and steel yield stress

Han et al, [10] demonstrated that the mid-span displacement and the impact duration decreased. While the plateau value of the impact force increased as increasing of the Steel's yield stress indicating that the member impact resistance increased. At variance concrete strength has very little influence on the member collision resistance because the most of section moment is responsible of the outer steel tube. Shakir et al, [14] concluded that the concrete strength change had less effect on the impact resistance than the steel's yield strength change, tube length and the outer diameter. They clarified that Total displacement decreased by 59.2% and the collision force increased by 133% with increasing the steel's yield strength from 250 MPa to 750 MPa. Li et al, [15] reported that the increase of steel strength was more effective in enhancing the collision resistance and decreasing the impact deformation of (RACFST) compared to increasing the strength of (RAC). While the increase of steel ratio was more effective than increasing them. Hu et al, [16] demonstrated that the strength of core concrete had less effect on the flexural capacity and the mid-span deflection compared to the steel's yield strength, the steel ratio and larger sectional diameter.

3.8. Boundary conditions

Han et al, [10] demonstrated that by constraining the end rotations, the plateau value of the impact force increased while the mid-span displacement and the impact duration decreased indicating that the impact resistance increased. They also reported that boundary conditions had an effect on CFST specimen failure modes. Bambach [5] found that specimens with no end rotational restraint showed less absorbed energy capacity than specimens with a full-end rotational restraint by (18%).

3.9. Effect of concrete infill and concrete type

Bambach et al, [1] observed that by the concrete filling, the absorbed energy decreased and the transverse failure deflection decreased which especially became more evident as the section slenderness increased. Remennikov et al, [3] demonstrated that the energy absorption capacity and the impact resistance of the concrete – filled tubes were the largest, followed by Rigid Polyurethane Foam (RPF) – filled tubes and then the hollow tubes. They also clarified that the foam – filled tubes had the least residual displacement then concrete – filled tubes and then hollow tubes. Bambach [5] clarified that concrete filling increased the moment capacity of hollow sections but in most cases the absorbed energy had been less. Deng et al, [6] explained that Posttensioned Concrete Filled Circular Steel Tubes (PTCFSTs) had the highest impact resistance then reinforced concrete – filled circular steel tubes (FRCFSTs) then (CFSTs). As a result, they clarified that (PTCFSTs) needed higher initial impact force to fracture than (FPCFSTs). In addition under the same initial collision energy, (PTCFSTs) showed the least maximum dynamic deflection then (FRCFSTs) then (CFSTs). Yousuf et al, [8] demonstrated that the Concrete-Filled Stainless Steel showed 45% higher impact load capacity than that of the hollow sections. They also concluded that the Concrete Filled Stainless Steels improved the local buckling resistance. Unlike the hollow sections that collapsed by local buckling before the global failure occurred. Han et al, [10] concluded that the inner concrete contributed to more ductile deformation modes for (CFST) than hollow steel tubes. As well as, it eliminated the incidence of local buckling in the steel tube.

From experimental results which had well agreement with the FEA model, Yang et al, [12] indicated that although the modulus of elasticity and compressive strength decreased while the slump increased by adding (RAC). They explained that (RACFST) specimens had better deformation – resistance capability as normal (CFST) specimens. Shakir et al, [14] indicated that the concrete filling improved the collision resistance and the resistance to indentation moreover decreased the global displacement. They also demonstrated that the (NACFST) columns had higher impact resistance than (RACFST) columns. Li et al, [15] indicated that with the increase of (RAC) content, the resistance to high temperature and the impact resistance of (RACFST) decreased. Hu et al, [16] indicated that Concrete – Encased Concrete – Filled Steel Tube columns showed better impact resistance, better reparability and lower residual deflection than (CFST) and (RC) columns.

3.10. Using stainless steel tube

Remennikov et al, [3] demonstrated that the stainless steel tubes had greater resistance to impact and capacity of energy absorption than mild steel tubes for hollow, concrete – filled and (RPF) – filled. Furthermore, it was recorded that the stainless steel had a high capacity for local plastic buckling which reduced the significant effect of the infilled concrete on its capacity. Bambach [5] clarified that the stainless steel specimen absorbed energy on average 1.8 times more than the energy absorbed by steel specimen. Yousuf et al, [8] clarified that Hollow and Concrete-Filled Stainless Steel has better strength and ductility compared with steel.

3.11. Use of Carbon Fiber Reinforced Polymer (CFRP) jackets

Alam et al, [13] indicated that strengthening concrete by (CFRP) sheets improved its impact resistance. Wherefore this study suggested utilizing this technique to avoid collapse of (CFST) column subjected to vehicular impact in bridges. Shakir et al, [14] demonstrated that with the usage of (CFRP) jackets, (RACFST) columns displayed equal impact resistance to (NACFST) columns. They also explained that the (CFRP) has a significant role in improving resistance to Displacement whereas one layer of the CFRP reinforcement had decreased displacement by about 8.3%.

3.12. Elevated temperature

Huo et al, [2] indicated that (CFST) exhibited excellent resistance to impact and excellent resistance to deformation under high temperature. Li et al, [15] explained that the impact deformation increased while the collision strength of (RACFST) improved with the temperature rise. They also clarified that the contribution of steel tube to improve the impact resistance at elevated temperature is higher than the contribution of (RAC) core.

4. Life-cycle performance of CFST subjected to impact loading

Hou and Han [27] numerically analyzed the life – cycle mechanical behavior of Concrete – Filled Steel Tubular (CFST) column subjects to transverse impact. The study included the construction stage passing through the several progressive degradations factors including the long term effects (creep and shrinkage) of concrete and the corrosion of steel tube then the extreme hazards (transverse impact load). They confirmed stage – by – stage the numerical model by experimental results. They defined the load-history for a (CFST) column during its lifecycle, (As illustrated in Fig. 4). The steel tube is erected during the construction stage and carried the load from the upper structure. The column begins its service life when the construction stage is completed (N_0). During its long-term lifecycle, the axial loading capacity of the (CFST) column gradually deteriorate and the axial displacement might increase due to the numerous progressive deterioration factors, such as the steel tube corrosion and the long-term effects (creep and shrinkage) of concrete. At a certain level, the (CFST) column is subject to impact lateral load which might crumble the axial loading capacity and cause further deformation. Assuming (CFST) column still stands after the impact load, it must predict its residual capacity (N_u) for evaluation and restoration purposes. They explained that the impact resistance and axial load strength gradually decrease as a result of corrosion (the reduction of steel ratio). Meaning that the lateral deflection is greater at the same impact energy as well as the residual compressive strength of column decrease. They also reported that in terms of load transfer between the core concrete and the steel tube, it seems that the corrosion effect is significantly weaker than the creep effect.

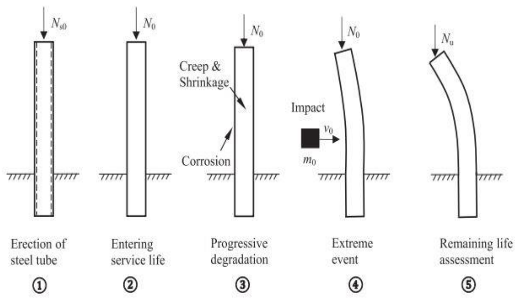

Fig. 4. CFST column load-history throughout its life cycle. (Hou and Han [27])

5. Failure modes of CFST under collision load

In general, failure modes of specimens varies according to boundary conditions, length of specimen, concrete filling or hollow, axial load level, confining factor, projectile configurations, thickness of tube and initial impact energy. Failure modes are in the form of the well-known plastic mechanism mode at mid-span and at fixed supports or local indentation, global displacement at mid-span (as illustrated in fig.4.) and local concrete crushing.

Yang et al, [12] clarified that there were three types of failure modes of (RACFST) under transverse impact load. The failure based on the variance of drop weight height (h), (RAC) replacement ratio (r) and axial load level (n) ; (1) specimen with axial load and small (h), steel tube showed only local buckling near the mid-span. (2) Specimen with axial load and an increasing (h), steel tube showed local buckling near the supports and the mid-span. (3) Specimen Without axial load, steel tube showed tensile fracture near the mid-span. As the effective confining provided by steel tube, it was found that crushing in concrete core at the mid span and shear cracks. As well as it was observed that specimens showed the plastic failure mechanism and along the span of tested specimens, three plastic hinges were formed. Hu et al, [16] explained the failure modes of Circular Concrete – Encased Concrete – Filled Steel Tube (CFST) columns under low velocity transverse collision. It was observed that the outer concrete had tensile cracks and crushed at bottom and top of mid-span section respectively. In addition, it had tensile cracks and crushed at top and bottom of the end-span section respectively. Local buckling was observed also in steel tube at the top of the mid-span section. Hou et al, [17] clarified the failure of Concrete-Encased Concrete-Filled Steel Tubular (CFST) box specimens. It showed the mode of shear-flexural failure with local concrete crushing under the impact energy which generated by the gravitational potential energy of an elevated hammer (E = mgh).

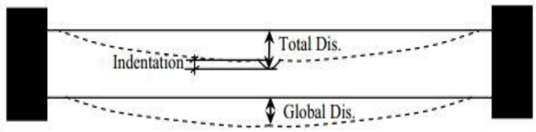

Fig. 5. The total and global displacements. (Shakir et al, [14])

6. Conclusion

This article review had discussed that the transverse impact process on hollow and Concrete Filled Steel Tubular (CFST) members and their dynamic response under impact loading, which revealed the following core findings:

- During impact loading at high strain rates, the tensile and compressive strengths both of the concrete and steel can significantly increase but the strain rate influence is neglected if the initial collision velocity is less than 10 m/s.
- The impact process can be categorized into three stages: peak stage, stable stage and unloading stage.
- At low axial load level, the impact force, impact resistance, critical fracture energy increase. On the contrary, the period of impact force and the lateral deflection decrease. While high level axial load had unfavorable effect on the impact resistance because of the load-moment interaction diagram of the section.
- With increasing the confining factor, critical fracture energy and impact resistance increase as (CFST) members behave in more ductile way.
- The change of concrete strength has less effect on the collision resistance and the

member's flexural capacity than the changes of yield strength, the outer diameter and tube length.

- The impact resistance and absorbed energy capacity increase by restraining the end rotations of the members.
- The concrete filling increase the indentation resistance and impact resistance in addition to reduce the global displacement.
- CFST showed an excellent impact resistance and an excellent deformation resistance under high temperature.
- Failure modes are in the form of the well-known plastic mechanism mode or local indentation, global displacement and local concrete crushing. On the other hand, failure modes of specimens varies according to boundary conditions, length of specimen, concrete filling or hollow, axial load level, confining factor, projectile configurations, thickness of tube and initial impact energy.

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