Comparative Study on Residual Capacity of Bridge Pier of 1% SFRC Pier with Conventional Concrete Pier Under Impact Loading

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***Abstract*: Vehicle strikes to bridge piers cause varied degrees of damage and a commensurate decline in structural strength. The amount of repairs needed to keep the bridge in use or whether to shut it down for pier replacement depends on the extent of the damage. In an effort to reduce the frequency of accidents, the bulk of the current studies in this field have adopted a risk management strategy. To establish if an object is suitable for further service, the majority of methods assign a damage level index. These methods, however, do not account for the pier's diminished capacity or its diminished ability to endure extra hazard loading situations like seismic. The study makes the assumption that each member will be operating at its design capacity when it encounters the hazardous loading because these sequential hazardous loading situations are not currently taken into account by the design regulations in use. In order to produce reduction factors that can be employed in the reliability analysis of a subsequent post-impact hazard analysis, this study aims to identify the loss in capacity that bridge piers experience as a function of vehicular impact.**

The Researchers of Wollo University used a normal conventional concrete pier with 1% extra SFRC Pier detail, which Kombolcha Institute of Technology University thoroughly explained in literature review. The damage index are evaluated using current techniques described in the literature, and the results are calculated with those of a typical concrete bridge pier. The reliability of the pier section is then assessed in relation to the mass, impact velocity, shape, and material qualities of the vehicle. The pier is also examined using numerical analysis methods to ascertain the post-impact residual axial and shear capacity. Finally, reduction factors that link to damage index that can be employed in future evaluation are found using the residual capacity.

Index Terms: **Peak Impact load, Residual Axial Capacity, Residual Shear Capacity, Vehicle Collision, Impact Mass, Impact Velocity, Equivalent Static Force, Nominal Shear Force.**

I. INTRODUCTION

One of the main reasons for bridge failure is vehicle contacted with bridge piers. There have been more studies on bridge pier crashes using finite element models as a result of the rise in vehicle-pier collisions over the past few years [1]. These crashes have severely damaged the bridge superstructure, as indicated in the bridge collapse in figure 1 and the fractured pier, while other collisions have only slightly damaged the piers, as illustrated in the concrete cracking at the impact site in figure 2 [1]. Therefore, it is essential to analyze the needs and damage mechanisms of concrete piers in order to improve the impact resistance of bridge piers and gives bridges a long service life.

Piers are essentially compression members that are primarily used to transfer axial loads via compression mechanisms. The purpose of longitudinal reinforcement in a pier is to absorb bending tensile stresses in that direction. However, when an automobile accident, the pier is subject to a transverse load. When transmitting this load, the pier will operate as a beam. However, when the load is transferred, cracks form and the pier deforms, losing its strength, ability to transfer axial loads, resistance to shear, etc. When a transverse force is applied, tension arises, hence the tension capacity of the piers is crucial. Because the main function of the pier is to transfer axial load by compression, improving tensile strength of the pier merely by adding longitudinal reinforcement is not a viable strategy. Therefore additional material which increases tensile as well as compressive strength is very important.

Figure 1: Bridge Collapse [1]

By bridging the tensile loads even at large crack holes through the pullout mechanism, the insertion of fibers significantly improves the ductility of the brittle damage process. These fibers efficiently stop the progression of the tiny cracks that are frequently observed in concrete from spreading. By bridging the cracks and distributing some of the weight across them, steel fibers in concrete lower the stress concentration at micro cracks. The mixing ratio, micro/macrostructure, geometrical characteristics, and mechanical properties of the steel fibers are all directly related to the strengthening mechanism.

Therefore, it would appear that SFRC is a potential replacement for traditional concrete in situations when impulsive intervention would prevent fragile collapse. Overall, the majority of these research focus on the analysis of SFRC beam behavior under impact loads. However, there has been little research done on how steel fiber-reinforced concrete piers behave and perform when subjected to impact loading. As a result, this study was carried out to evaluate how well SFRC piers performed under impact loading. Additionally, it investigated the characteristics of damaged piers and their failure patterns as well as the factors that can seriously harm bridge piers. Comparing numerical displacements, impact data, and the pier models.

Experimental findings of the drop hammer impact test on SFRC beams including forces, crack patterns, and impact data. The experiments performed by Jin et al. [1] were used in this investigation to validate the material properties and finite element controls for the pier simulations under impact load. In order to investigate the impact parameters effects and the behaviour of reinforced concrete piers during vehicle crashes, a parametric analysis based on the validated numerical was carried out.

Parameters: Once the numerical model is validated, a parametric study was conducted to examine the influence of impact parameters and the behaviour of reinforced concrete piers subjected to impact load. These parameters include impact mass, impact velocity, the volume of steel fibers, concrete grade, and percentage of longitudinal reinforcement. The summarized information of the studied parameters is presented in Table no. 1.

Table No. 1: Parameters

I.M. (T)	I.V. (Km/hr)	Vol. SFRC (%)	Conc. Grade (Mpa)	Percentage of Lf Reinforcement (%)
3.5	30	0	30	0.9
3.5	60	0	30	0.9
3.5	90	0	30	0.9
3.5	30	1	30	0.9
3.5	60	1	30	0.9
3.5	90	1	30	0.9
10	30	0	30	0.9
10	60	0	30	0.9
10	90	0	30	0.9
10	30	1	30	0.9
10	60	1	30	0.9
10	90	1	30	0.9
30	30	0	30	0.9
30	60	0	30	0.9
30	90	0	30	0.9
30	30	1	30	0.9
30	60	1	30	0.9
30	90	1	30	0.9
60	30	0	30	0.9
60	60	0	30	0.9
60	90	0	30	0.9
60	30	1	30	0.9
60	60	1	30	0.9
60	90	1	30	0.9

I.M: Impact Mass

I.V.: Impact Velocity

Impact Mass: - For studying the detailed effect of mass on bridge pier. Actual mass of vehicles are considered such as 3.5T, 10T, 30T and 60T.which represents the different categories of vehicles such as Light

Commercial Vehicles (LCV), Medium Commercial Vehicles (MCV), and Heavy Commercial Vehicles (HCV). All these masses are acted with different velocities for Proper impact effect.

Impact Velocity: - For studying the detailed effect of mass on bridge pier actual velocities of vehicles are considered such as 30Kmph, 60Kmph, and 90Kmph which represents the speed of different vehicles in different situations.

Volume of SFRC: - To compare the effect of impact on 0% SFRC concrete and 1% SFRC added concrete is used. To prepare SFRC the amount of steel fiber was selected by 1% volume of concrete i.e. 78kg/m^3. This concentration of steel fiber was selected based on maximum mechanical ductility output. For FEM study previous experimental researches are adopted which are based on water cement ratio, sand, coarse aggregate, fiber type, fiber physical properties etc. all fiber properties are described in table no 2. And shown in figure 2.

Table No.2: Physical Properties of Steel Fiber

L MM	D MM	Aspect Ratio	Tensile Strength MPa	Density g/cm^3	Shape
30	0.6	50	1100	7.8	Hooked

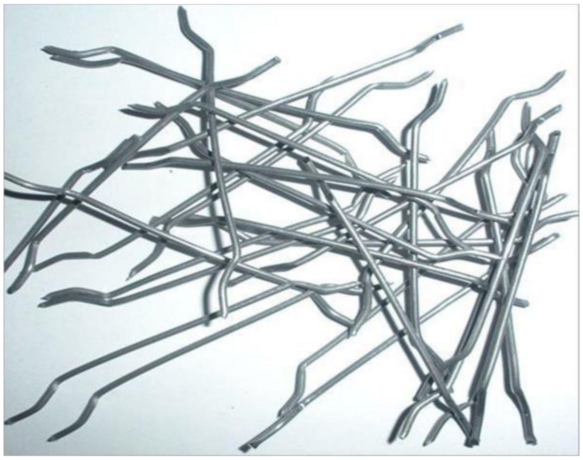


Figure 2: Steel Fiber [https://www.google.com/url?sa=i&url=https%3A%2F%2Fconnect2india.com%2FSteel-Fibres&psig]

Pier Specification: As shown in figure 3 and table 3 detailed specification is given according to Melaknesh.et.al.[1]. From these specifications all the models are prepared in FEM.

Table No.3: Design values of Reinforced Concrete Pier [1]

H M	D MM	Strength	L. Rf	Stirrup	Rf. Ratio
2.8	400	30	3φ25mm and 2φ16mm	8mm	0.9

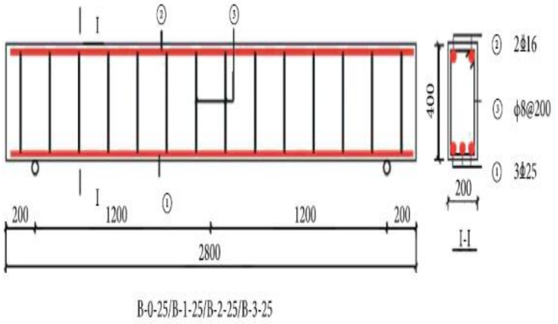


Figure No. 3: Dimensions and Reinforcement layout of RC and SFRC beam

II. ASSEMBLY AND FEM

In this study, the bridge pier is prepared in ABAQUS-2023 details were taken from Melaknesh et al. [19]. The finite element pier model is shown in Figure 3.3, and design values are listed in Table 3.4. To study the impact behaviour of RC and SFRC bridge pier, different FE pier models were analyzed. 'The effective height of the pier is 2.8 m. The depth of the pier is 0.4 m. As shown in Table 3, all specimens were modaled with the same cross-sectional area and effective height. The physical properties of steel fiber are chosen from Table 2. Concrete and steel were modaled by solid and beam elements respectively. The mesh size of each element is 25mm x25mm. In addition, this modal allows the user to specify a complete set of model parameters from the material test data. The concrete damage model is a three-invariant model that uses three shear failure surfaces and includes strain rate and damage effects. It handles the volumetric and deviatory responses separately, as often done by explicit codes. This material model is a plasticity-based formulation with three independent surfaces which change shape based on pressure. The values shown in Table 4A, 4B, 4C, 4D, were adopted in this study.

Table No. 4A: Material Properties

Parameters	Concrete Damage
	0%
Yield Strength (Mpa)	
Density (Kg/m^3)	2500
Elastic Modulus (GPa)	27.38
Poisson's Ratio	0.2
Compressive Strength (Mpa)	30

Table No. 4B: Material Properties

Parameters	Concrete Damage
	1%
Yield Strength (Mpa)	
Density (Kg/m^3)	2500
Elastic Modulus (GPa)	30.7
Poisson's Ratio	0.2
Compressive Strength (Mpa)	36.7

Table No. 4C: Material Properties

Parameters	Steel
	Longitudinal Bar
Yield Strength (Mpa)	400
Density (Kg/m^3)	7850
Elastic Modulus (GPa)	200
Poisson's Ratio	0.3
Compressive Strength (Mpa)	

Table No. 4D: Material Properties

Parameters	Steel
	Stirrup
Yield Strength (Mpa)	300
Density (Kg/m^3)	7850
Elastic Modulus (GPa)	200
Poisson's Ratio	0.3
Compressive Strength (Mpa)	

The numerical modal of the impact test was developed in ABAQUS 2022 and is shown in Figure 4. Table 4 shows the properties of concrete and reinforcement bar used in ABAQUS 2022. Concrete and steel fiber were modeled by CONCRTE_DAMAGE_REL3. The reinforcement bar was modeled by MAT_PLASTIC_KINEMATIC. The contact type between drop hammer and beam was AUTOMATIC SURFACE TO SURFACE.

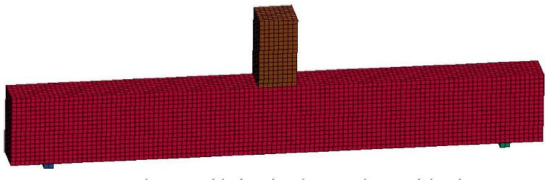
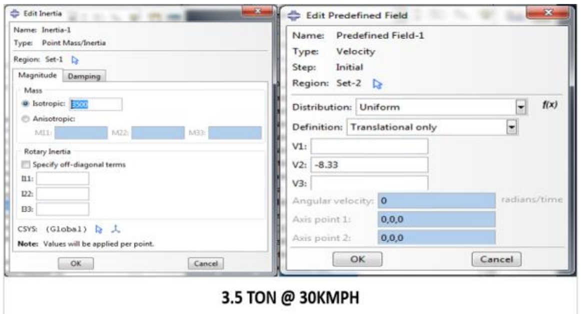


Figure No. 4: Finite element model of reinforced concrete beam and drop hammer

III. LOADING CONDITION

Inertia of engineering features from assembly is used to assign mass (mass is given in kg converted from ton) to the hammer and predefined fields are used to assign velocity to drop hammer (velocity is given in m/s converted from kmph).

As shown in figure 5, mass and velocity is provided to all the 12 models of each type of concrete and its corresponding deformation is obtained.



Edit Inertia

Name: Inertia-1

Type: Point Mass/Inertia

Region: Set-1

Mass

● Isotropic: 3500

○ Anisotropic:

Rotary Inertia

☐ Specify off-diagonal terms

CSYS: (Global)

Note: Values will be applied per point.

Edit Predefined Field

Name: Predefined Field-1

Type: Velocity

Step: Initial

Region: Set-2

Distribution: Uniform

Definition: Translational only

V1:

V2: -8.33

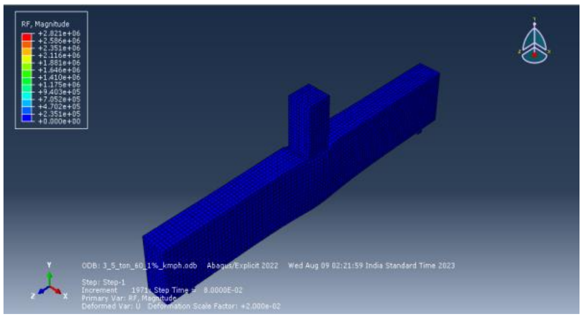
V3:

Angular velocity: 0 radians/time

Axis point 1: 0,0,0

Axis point 2: 0,0,0

3.5 TON @ 30KMPH



ODB: 3_5_ton_60_1%_kmph.odb Abaqus/Explicit 2022 Wed Aug 09 02:21:59 India Standard Time 2023

Step: Step-1

Increment 1971: Step Time = 8.0000E-02

Primary Var: RF, Magnitude

Deformed Var: U Deformation Scale Factor: +2.000e-02

Figure No. 4: 3.5 TON @ 30KMPH

IV. RESIDUAL CAPACITY CALCULATION STEPS

(A) Calculation of Design Axial Force Pndesign

P = σcc × Ac + σcc Asc ……. As per IS 456-2000

Asc = (π/4 ×$Ø^2$) + (2×π/4×$Ø^2$)

Ag = B×D

Ac = Ag - Asc

For M30 Concrete, σcc = 8 N/mm2

For Fe400, σsc = 190 N/mm2

leff⁄b > 12 Hence long column as per IS code.

Column is long column. So applying reduction factor

Cr = 1.25 - L⁄48b

(B) Calculation of Permissible Shear Stress in Concrete

(100 As)/(b*d)

As per IS 456:2000

Table 5: Permissible Stress

$\frac{100\ As}{b*d}$	M 30
2.25	0.55
2.35	x
2.50	0.57

(C) Residual Capacity Calculation

$$\text{LESF} = \left(\int_{tp-25}^{tp+25} Pi\ Di\right)/50$$

LESF:- Local Equivalent Static Force
Pi= P sin(πi/t)
Pi:- Instantaneous Impact Force

$$\text{DIF} = n = 1+\sqrt{1+\frac{2\times10}{\Delta}}$$

DIF:- Dynamic Impact Force
Idyn = LESF × DIF
Idyn:- ESF from impacting vehicle
Vn = Vc + Vs
Vn:- Design Shear Capacity
Vdyn = Vn × DIF
Vdyn:- Dynamic Shear Capacity
ʎ = Idyn / Vdyn
ʎ :- Damage Index
ʎ = 1- Presidual/Pdesign

By these steps Residual Capacity is calculated in this Paper.

V. RESULTS

(A) Peak Impact Force Developed

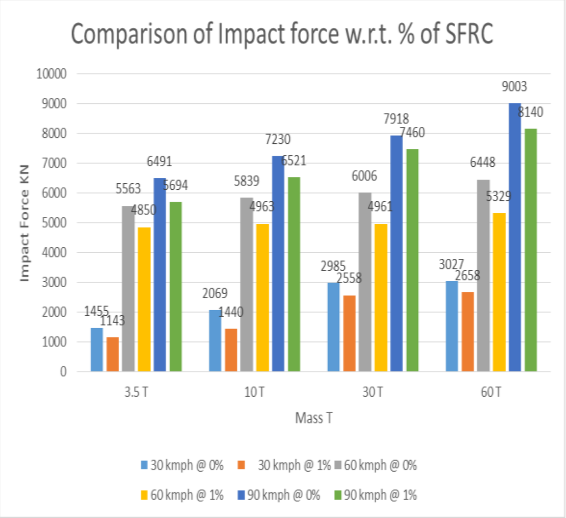


Figure 5: Comparison of Impact Forces Developed

To do comparative study of impact force developed graph is plotted as shown in figure:5 for impact force against mass for 0% SFRC and 1% SFRC Pier.

(B) Residual Axial Capacity

To do comparative study of residual axial capacity graph is plotted as shown in figure:6 for residual axial capacity against mass for 0% SFRC and 1% SFRC Pier.

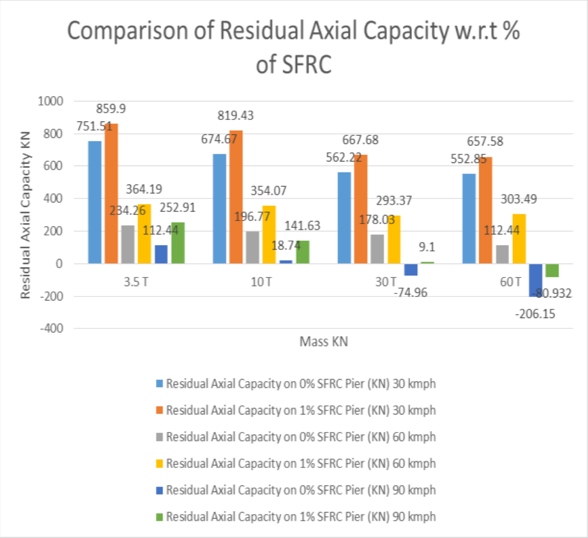


Figure 6: Comparison of Residual Axial Capacity

(C) Residual Shear Capacity

To do comparative study of residual shear capacity graph is plotted as shown in figure 7 for residual shear capacity against mass for 0% SFRC and 1% SFRC Pier.

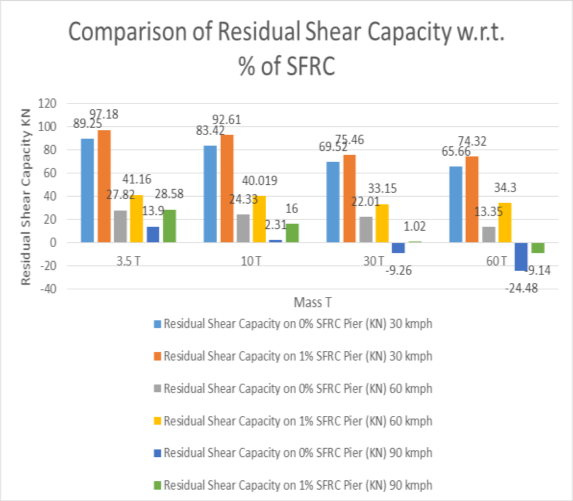


Figure 7: Comparison of Residual Shear Capacity

(D) Damage Index

To do comparative study of damage index graph is plotted as shown in figure 8 for damage index against mass for 0% SFRC and 1% SFRC Pier.

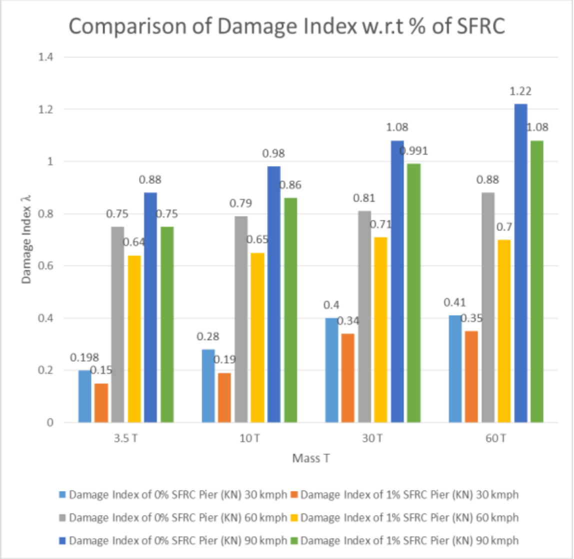


Figure 8: Comparison of Damage Index

(E) Peak Capacity Ratio: - To do comparative study of Peak capacity ratio graph is plotted as shown in figure 9 for damage index against mass for 0% SFRC and 1% SFRC Pier. From the figures, it can be inferred that as the dynamic impact increases, there is a linear decrease in the pier axial load ratio. But for 0% SFRC Pier axial load ratio is less than 1% SFRC Pier.

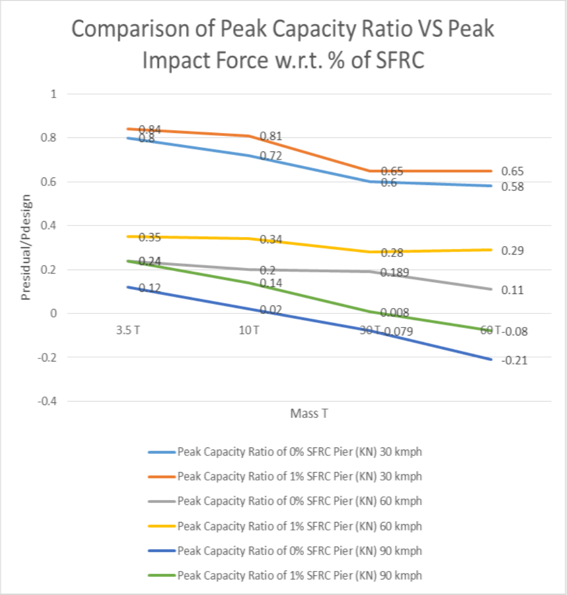


Figure 9: Comparison of Peak Capacity Ratio

VI CONCLUSION

(A) Impact Force Developed

From results obtained for 0% SFRC pier and 1% SFRC pier of peak impact force developed. We get to see that on conventional RC pier peak impact force developed is more than peak impact force developed on 1% SFRC pier. This is because after adding 1% SFRC Young's modulus of SFRC pier increased. Increased Young's modulus prolongs the elastic limit and yield because Young's modulus is ratio of stress and strain. Increased elastic limit means softening of material, which gives less reaction force.

(B) Residual Axial Capacity

Due to prolonged elastic limit and yield point, tension carrying capacity of 1% SFRC pier increased. In transverse direction impact load, major tension develops on pier. Therefore 1% SFRC pier perform well in impact. By comparing calculated residual axial capacities we can say that reduction in axial capacity for convention RC pier is more than reduction in axial capacity for 1% SFRC pier. As the velocities and impact mass increased it shows similar trend. Always percentage of reduction in axial capacity with respect to designed axial capacity is more for conventional RC pier than 1% SFRC pier.

(C) Residual Shear Capacity

Due to prolonged elastic limit and yield point, tension carrying capacity of 1% SFRC pier increased. In transverse direction impact load, major tension develops on pier. Therefore 1% SFRC pier perform well in impact. By comparing calculated residual shear capacities we can say that reduction in shear capacity for conventional RC pier is more than reduction in shear capacity for 1% SFRC pier. As the velocities and impact mass increased it shows similar trend. Always percentage of reduction in shear capacity with respect to designed shear capacity is more for conventional RC pier than 1% SFRC pier.

(D) Damage Condition

To study the actual damage of pier, its damage index is calculated and studied for each impact mass and its corresponding velocity.

0% SFRC Pier @ 30kmph reaches upto medium damage for 30T impact mass whereas 1% SFRC Pier stays in low damage until 60T @ 30kmph.

0% SFRC Pier @ 60kmph reaches upto high damage for 10T impact mass whereas 1% SFRC Pier stays in medium damage until 60T @ 60kmph.

0% SFRC Pier @ 90kmph reaches upto total collapse for as early as 3.5T impact mass whereas 1% SFRC Pier reaches to total collapse at 10T @ 90kmph.

For conventional pier acted by 3.5T @ 90kmph complete replacement is required but 1% SFRC Pier requires replacement for 10T @ 90kmph.

By above all discussion we can conclude that using 1% steel fiber in concrete will give better results in every situation.

REFERENCES

1.Mechanical properties of SFRC: Database construction and model prediction, Yumei Wanga, Hemao Jinb, Cristoforo Demartinoc, Wenguang Chena, Yong Yud, Department of Structural Engineering, Tongji University, Shanghai 200092, China, China Construction Fifth Division Southern Construction Subsidiary Corp., LTD, Shenzhen
2.Vehical Impact Damage of reinforced concrete bridge piers: A state of the art review, S. Roy, S. M. ASCE, I. Unobe, S. M. ASCE, A. D. Soren, American society of civil engineers.
3.Analysis assessment and Mitigation of Barge impact load on bridge piers, Yanyan Sha, The University of Western Australia.
4.Non Linear fiber element modelling of RC Bridge piers considering inelastic buckling of reinforcement, Mohammad M Kashani, Adam John Crewe, University of Southhampton
5.Residual Capacity of Impacted Bridge Piers, Andrew Sorensen, Ph.D.Marvin Halling, Ph.D, Department of Civil and Environmental Engineering, Utah State University
6.A study of impact damages detection and dynamic response of RC Bridge piers based on a frequency domain correlation method, Xiwu Zhou, Jingdong Liu, Xiaolu Deng,
7.Analysis of Dynamic Response on Double column bridge piers of mountains area based on the collision of rolling stones, Wang Zijian, Zhang Jianing, Hu Jiapeng, Yang Bo, Wu Lining, School of Architecture and Engineering, Chongging University of Science and Technology, China
8.Performance of Steel Fiber-Reinforced Concrete Pier under Impact Load, Melaknesh Dessalegn®' and Temesgen Wondimu "Civil Engineering, Wollo University, Kombolcha Institute of Technology, Kombolcha,
9.Impact Load Factors for Static Analysis, Prof. J.E. Akin, Rice University