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# Assessment of Residual Capacity of Bridge Pier with added Steel Fibre after Impact Loading: A Review

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**ABSTRACT:** This study seeks to identify the reduction in capacity that bridge piers experience as a function of vehicular impact to develop reduction factors that can be used in the reliability analysis of subsequent, post impact, hazard analysis. Using a standard conventional concrete pier and 1% added SFRC Pier detail utilized by the researchers of Wollo University, kombolcha institute of Technology University fully described in literature review. Existing methods available in the literature are used to evaluate the damage indices and to compare those results to results of conventional concrete bridge pier. The reliability of the pier section is then determined as a function of material properties, geometry, vehicle mass, and vehicle impact velocity. Using numerical analysis techniques, the pier is also analysed to determine the residual axial and shear capacity post-impact. Finally, the residual capacity is used to determine reduction factors that correlate to damage indices that can be used in future evaluation.

**KEYWORDS:** Peal Impact, Peak Capacity Ratio, Damage Index, Residual Shear Capacity, Residual Axial Capacity.

## 1.INTRODUCTION

Vehicle collision of bridge piers is one of the leading causes of bridge failure. Due to the increase in vehicle-pier collisions in the past few years, there has been an increase in the number of studies on bridge pier collisions using finite element simulations [1]. These collisions have caused severe damage to bridge structures, such as bridge collapse as shown in figure 1.1 and pier fracture, while other accidents have caused slight damage to piers, such as cracking of concrete as shown in figure 1.2 at the impact location [1]. Therefore, it is necessary to improve the impact resistance of bridge piers to give bridges a long service life and to study the requirements and damage modes to concrete piers.



Figure 1: Bridge Collapse



Figure 2: Collision

The addition of fibers is an alternative technique to enhance the impact resistance of bridge piers. Fiber-reinforced concrete (FRC) is a cement-based composite reinforced with discrete fibers that are usually randomly distributed. Fibers are added to the concrete mixture to bridge discrete cracks, thus increasing the control of the fracture process, also increasing the fracture energy, and providing more ductile behaviour. Fiber-reinforced concrete (FRC) has been

demonstrated to exhibit superior resistance to high strain rate loads compared to conventional concrete, in addition to better control of plastic shrinkage and crack expansion. Therefore, fiber-reinforced concrete is more typically employed to resist impact or blast loads in designed structures.

## II. LITERATURE REVIEW

Melaknesh Dessaleg, Temesgen Wondimu *et.al.* Vehicular impact on bridge piers is one of the leading causes of bridge failure. Due to the increase in vehicle-pier collisions, many researchers have studied the performance of RC bridge piers under vehicle collisions. Adding steel fiber is an alternative way to improve the impact resistance of concrete structures and enhance their capacity for energy absorption. However, a study on the performance of piers with steel fiber-reinforced concrete under impact load is limited. This study examines the performance of steel fiber-reinforced concrete (SFRC) bridge piers subjected to impact loading. To study the impact behaviour of SFRC piers, a numerical model of bridge piers with impact mass was developed by LS-DYNA. The reliability of the numerical analysis was validated. To investigate the effects of impact mass, impact velocity, the volume of steel fiber, concrete grade, and percentage of longitudinal reinforcement on the impact behaviours of piers and the impact forces, parametric studies were carried out. The finite element analysis revealed that the addition of steel fiber resists lateral deformation and significantly affected the failure modes of bridge piers under impact loading. Moreover, the deformation of the impacted piers and the impact force is mainly affected by the addition of steel fiber, impact energy, and percentage of longitudinal reinforcement and is not sensitive to concrete strength.

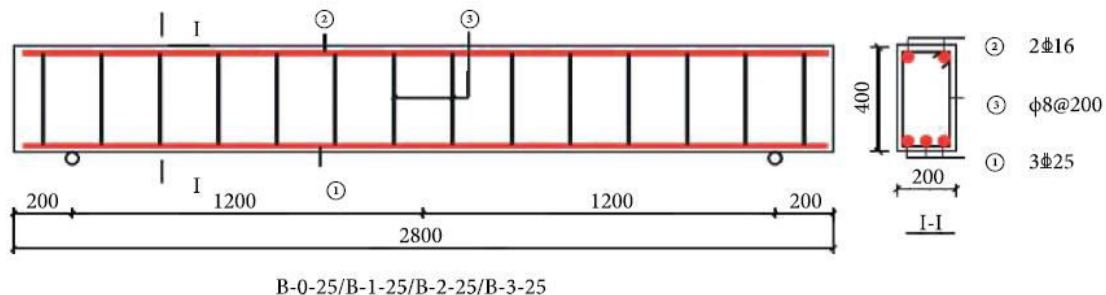


Figure 3: Dimensions and Reinforcement layout of RC and SFRC beam

S. Roy, I. Unobe, A. D. Sorensen *et.al.* Designated the local equivalent static force (LESF), this modification involved integrating the impact force over a 50 millisecond window around the force and then averaging by 50 milliseconds (Zhou and Li, 2018). By limiting the integral to a shorter window, the effect of both the time frame and the PIF on the impact scenario are adequately included in the model, localizing the effect of the impact force to a shorter range of time it is expected to have occurred in. The 50-millisecond window was selected with reference to the 50-millisecond moving average often used to extrapolating the impact time history curve in vehicle crash analyses (Buth et al., 2011). The revised model (LESF) is as shown in Equation 2.11 (Zhou and Li, 2018).

$$LESF = \frac{\int_{t-25}^{t+25} P_i di}{50}$$

$$P_i = P \sin\left(\frac{\pi i}{t}\right)$$

Shear strength of concrete members, produced a nominal design shear strength ( $VV_{nn}$ ) equation.

$$V_n = V_c + V_s$$

$$V_c = \sigma_c [1 + 3P / (f'_c * A_g)] A_e$$

An alternative method used in computing the damage index is a ratio of the equivalent static force to the shear capacity of the pier. Shown in Equation 2.41, this method allows for the computation of the damage index ( $\lambda$ ) irrespective of the method used in estimating the ESF (Zhou and Li, 2018).

$$\lambda = I_{dyn} / V_{dyn}$$



The dynamic shear,  $V_{dyn}$ , the dynamic impact factor, and shear capacity of the column,  $V_n$ , are related by the relationship in Equation

$$V_{dyn} = V_n \cdot (DIF)$$

The relationship between the damage index and residual strength of the damaged column is shown in Equation

$$\lambda^{1-P} N_{residual}^P N_{design}$$

Is 456:2000 Plain And Reinforced Concrete - Code Of Practice

This standard deals with the general structural use of plain and reinforced concrete. For the purpose of this standard, plain concrete structures are those where reinforcement, if provided is ignored for determination of strength of the structure. Special requirements of structures, such as shells, folded plates, arches. Bridges, chimneys, blast resistant structures, hydraulic structures, liquid retaining structures and earthquake resistant structures, covered in respective standards have not been covered in this standard; these standards shall be used in conjunction with this standard.

Clause 8-5.2 Design Shear Strength of Concrete:- The permissible shear stress in concrete in beams without shear reinforcement is given in Table 1

Table No. 1: Permissible Shear Stress in Concrete

$100 \frac{A}{bd}$	Permissible Shear Stress in Concrete, $\tau_c$ , N/mm <sup>2</sup>					
	Grade of Concrete					
	M 15	M 20	M 25	M 30	M 35	M 40 and above
(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\leq 0.15$	0.18	0.18	0.19	0.20	0.20	0.20
0.25	0.22	0.22	0.23	0.23	0.23	0.23
0.50	0.29	0.30	0.31	0.31	0.31	0.32
0.75	0.34	0.35	0.36	0.37	0.37	0.38
1.00	0.37	0.39	0.40	0.41	0.42	0.42
1.25	0.40	0.42	0.44	0.45	0.45	0.46
1.50	0.42	0.45	0.46	0.48	0.49	0.49
1.75	0.44	0.47	0.49	0.50	0.52	0.52
2.00	0.44	0.49	0.51	0.53	0.54	0.55
2.25	0.44	0.51	0.53	0.55	0.56	0.57
2.50	0.44	0.51	0.55	0.57	0.58	0.60
2.75	0.44	0.51	0.56	0.58	0.60	0.62
3.00 and above	0.44	0.51	0.57	0.60	0.62	0.63

NOTE —  $A$ , is that area of longitudinal tension reinforcement which continues at least one effective depth beyond the section being considered except at supports where the full area of tension reinforcement may be used provided the detailing conforms to 26.2.2 and 26.2.3.

Clause B-3 PERMISSIBLE LOADS IN COMPRESSION MEMBERS

Pedestals and Short Columns with Lateral Ties

The axial load  $P$  permissible on a pedestal or short column reinforced with longitudinal bars and lateral ties shall not exceed that given by the following equation:

$$P = \sigma_{cc} A_c + \sigma_{sc} A_s$$

Long Columns: The maximum permissible stress in a reinforced concrete column or part thereof having a ratio of effective column length to least lateral dimension above 12 shall not exceed that which results from the multiplication of the appropriate maximum permissible stress as specified:

$$C_r = 1.25 - \frac{L_{ef}}{48 b}$$



Value of permissible stresses in concrete and steel are taken from table 2 and 3 which is taken from IS456:2000

Table No. 2: Permissible Stresses in Concrete

Grade of Concrete	Permissible Stress in Compression		Permissible Stress in Bond (Average) for Plain Bars in Tension
	Bending	Direct	
(1)	(2)	(3)	(4)
	$\sigma_{cb}$	$\sigma_{cd}$	$\tau_{cb}$
M 10	3.0	2.5	—
M 15	5.0	4.0	0.6
M 20	7.0	5.0	0.8
M 25	8.5	6.0	0.9
M 30	10.0	8.0	1.0
M 35	11.5	9.0	1.1
M 40	13.0	10.0	1.2
M 45	14.5	11.0	1.3
M 50	16.0	12.0	1.4

NOTES

- 1 The values of permissible shear stress in concrete are given in Table 23.
- 2 The bond stress given in col 4 shall be increased by 25 percent for bars in compression.

Table 3: Permissible Stresses in Steel Reinforcement

Sl No.	Type of Stress in Steel Reinforcement	Permissible Stresses in N/mm <sup>2</sup>		
		Mild Steel Bars Conforming to Grade I of IS 432 (Part 1)	Medium Tensile Steel Conforming to IS 432 (Part 1)	High Yield Strength Deformed Bars Conforming to IS 1786 (Grade Fe 415)
(1)	(2)	(3)	(4)	(5)
i)	Tension ( $\sigma_{st}$ or $\sigma_{stc}$ )			
	a) Up to and including 20 mm	140	Half the guaranteed yield stress subject to a maximum of 190	230
	b) Over 20 mm	130		230
ii)	Compression in column bars ( $\sigma_{sc}$ )	130	130	190
iii)	Compression in bars in a beam or slab when the compressive resistance of the concrete is taken into account	The calculated compressive stress in the surrounding concrete multiplied by 1.5 times the modular ratio or $\sigma_{sc}$ whichever is lower		
iv)	Compression in bars in a beam or slab where the compressive resistance of the concrete is not taken into account:			
	a) Up to and including 20 mm	140	Half the guaranteed yield stress subject to a maximum of 190	190
	b) Over 20 mm	130		190

NOTES

- 1 For high yield strength deformed bars of Grade Fe 500 the permissible stress in direct tension and flexural tension shall be  $0.55 f_y$ . The permissible stresses for shear and compression reinforcement shall be as for Grade Fe 415.
- 2 For welded wire fabric conforming to IS 1566, the permissible value in tension  $\sigma_{st}$  is  $230 \text{ N/mm}^2$ .
- 3 For the purpose of this standard, the yield stress of steels for which there is no clearly defined yield point should be taken to be 0.2 percent proof stress.
- 4 When mild steel conforming to Grade II of IS 432 (Part 1) is used, the permissible stresses shall be 90 percent of the permissible stresses in col 3, or if the design details have already been worked out on the basis of mild steel conforming to Grade I of IS 432 (Part 1), the area of reinforcement shall be increased by 10 percent of that required for Grade I steel.

### III. STUDY

As stated in above reviews we can clearly say that it is possible to do assessment study of residual capacity of bridge pier after impact loading. This study can be done totally by manual calculations by using various formulae available. But to get accuracy, mixed study of FEM analysis and manual calculation may give better results.

To do analysis on any FEM software can be used such as ABAQUS,LS-DYNA etc. on that model of pier analysis gives various results of different parameters. For our study reaction force developed is obtained from FEM analysis. Then that reaction force is used to calculate the actual impact force acted on bridge pier due to impact velocity and mass. Furthermore equivalent static force is calculated to carry out the study because static analysis gives best results. ESF is calculated as per given equation. Dynamic impact factor is calculated to match the static results to dynamic results. Design axial capacity and design shear capacity is calculated. Then dynamic shear capacity and dynamic axial capacity calculated from given equation from this damage index is calculated. From damage index residual axial capacity and residual shear capacity is calculated by given equation.

### IV. CONCLUSION

In RC bridge structural members, piers are usually very susceptible to vehicle collisions. However, the prevailing design provisions of those members against vehicle collisions need additional study, with the expected performances during collisions not well defined. There is a need for a comprehensive framework for assessing the vulnerability of existing structures to such collisions and proffering solutions to limit such vulnerabilities.

This research attempts to provide a comprehensive insight for developing methodologies and studies aimed toward characterizing the damage sustained by RC bridge piers after collisions with vehicles. Various performance-based studies were examined for an ideal method to predict the intensity of damage. Additionally, an effort at categorizing different failure patterns consistent with severity was presented during which specific damage levels pertaining to localized action of impact along with the surface concrete spalling are correlated to different performance levels.

Supported by the numerical analyses results from several studies, the recommended value of the ESF within the impact design provisions of standard codes seems to come short of possible impact forces, which could end in piers designed with these codal provisions being susceptible to substantial impact forces. Alternative methods proposed for determining the ESF were presented and damage indices to quantitatively classify the severity of damage from impact discussed. However, more simulation studies and field tests are necessary to establish an inspection protocol that will accurately quantify the damage to an RC pier from impact and improve decision making on what needs to be done to return the damaged pier to a serviceable condition.

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