

Analysis And Design Of Precast Concrete Pier Systems For Rapid Construction Of Bridges In Seismic Zone-V

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Abstract- Precast piers in bridge construction represent a modern and efficient solution, offering advantages in terms of construction speed, structural reliability, cost-effectiveness, and reduced site disruption. Recent advancements in seismic-resisting systems for precast reinforced concrete bridge piers highlight their growing relevance in sustainable urban environments exposed to moderate to high seismic activity. The increasing demand for rapid bridge construction—driven by aging infrastructure and rising traffic volumes—has accelerated the adoption of precast systems as viable alternatives to traditional cast-in-place methods. Precast components offer several benefits, including faster construction, improved quality control, enhanced worker safety, reduced environmental disruption, and lower life-cycle costs. A key focus in the literature is the detailing of connections, which is critical to achieving seismic resilience. The incorporation of mild steel deformed bars to connect precast elements has demonstrated effectiveness in enabling energy dissipation and ductile performance under lateral seismic loads. Advanced nonlinear finite element analyses have been widely used to assess displacement capacities, damage patterns, and global seismic response of precast piers. Despite this progress, there remains a need for practical, design-oriented approaches that accurately estimate seismic displacement demands, particularly methods incorporating cracked-section behaviour and base-shear strength ratios. This review identifies ongoing research gaps and underscores the importance of developing simplified analytical tools and parametric models to facilitate efficient seismic design and performance evaluation of precast concrete bridge pier systems

Keywords- Precast Pier, bridge pier, rapid construction, IRC-6 loading, STAAD Pro.

I. INTRODUCTION

Precast bridge piers are increasingly used in modern bridge construction, particularly for river crossings, highways, and locations with complex grade changes where rapid construction and spatial efficiency are essential. As urban areas grow more congested and infrastructure demands

become more intricate, precast solutions offer a practical alternative to conventional cast-in-place methods. Their popularity stems from numerous benefits, including reduced construction time, improved safety, enhanced durability, and better-quality control. In scenarios where in-situ construction is limited by environmental concerns, economic factors, or restricted access, precast piers provide a sustainable and efficient option. Modern roadways, designed for high-speed travel and increased safety, require uninterrupted alignments and minimal disruption during construction. Precast piers support these goals by enabling faster project delivery and minimizing on-site activity. However, the structural behaviour of bridges supported by precast piers can be complex, especially in long-span applications or when subjected to dynamic loads. Although a growing number of studies have explored the performance of precast components, there is still a lack of comprehensive design guidelines for their use in diverse site conditions. Numerous variables—such as geometry, joint detailing, material variability, and construction tolerances—affect their performance. This highlights the need for further research into the behaviour and optimization of precast pier systems under varied loading and environmental conditions.

Characteristics of Precast pier

Precast bridge piers are essential components in modern bridge construction, offering a combination of structural efficiency, durability, and construction convenience. These piers are fabricated off-site in controlled environments and then transported to the construction location for assembly, which provides numerous advantages over conventional cast-in-place construction. One of the primary characteristics of precast piers is enhanced construction speed. Since fabrication and site preparation can occur simultaneously, project timelines are significantly reduced. This is particularly beneficial in urban areas or critical infrastructure projects where minimizing traffic disruption is a priority. Quality control is another significant benefit. Precasting in a factory setting ensures consistent material properties, accurate dimensions, and reduced variability, leading to improved structural performance and long-term durability. Additionally,

worksite safety is enhanced because less formwork, labour, and equipment are required on-site

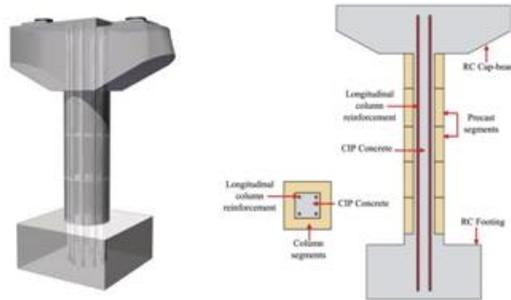


Figure 1: Precast pier with pier cap and footing

Precast piers also exhibit modular construction capability, allowing for flexibility in design and ease of replacement or upgrading. Components such as pier shafts, caps, and footings can be prefabricated in standard sizes or customized as needed. Their repeatability makes them ideal for large-scale projects with uniform design requirements. Structurally, precast piers are designed to resist vertical loads from the superstructure, as well as lateral forces from wind, seismic activity, and vehicle impact. They are typically reinforced with steel to handle tensile stresses and may incorporate post-tensioning for added strength and crack control. However, the performance of connections between precast elements is critical. Proper detailing and execution of joints—often using grouted couplers, dowel bars, or welded connections—are necessary to ensure monolithic behaviour and load continuity. Another characteristic is their reduced environmental impact. Precasting reduces on-site material waste, limits construction noise and dust, and minimizes disturbance to the surrounding area—making it more sustainable, especially in ecologically sensitive regions. Despite their many advantages, challenges include transportation logistics, handling of large units, and the need for precise alignment and assembly. Nonetheless, with proper planning and engineering, precast piers offer a reliable, efficient, and sustainable solution for a wide range of bridge applications. Continued research and innovation in connection detailing and seismic resilience further enhance their role in modern bridge infrastructure.

Scope of proposed study

The scope of this study is to develop a safe, efficient, and durable precast concrete pier system specifically designed for rapid bridge construction in Seismic Zone-V regions. The research will focus on identifying suitable precast systems, analyzing their behavior under various load combinations as per IRC 6:2017, and evaluating both static and dynamic responses. It will also include seismic performance assessment to estimate potential damage under Zone-V conditions. The

study aims to contribute to the advancement of design and engineering practices, promoting the use of precast technologies that ensure structural safety, construction efficiency, and long-term durability in seismic environments.

Objectives:

- To identify and evaluate suitable precast concrete piersystems. Examine available precast pier technologies and assess their applicability in seismic zones for improved resilience and construction efficiency.
- To analyze the effects of various loads on the pier system as per IRC 6:2017. Study the influence of dead, live, wind, and seismic loads on the structural behavior of piers based on IRC 6:2017 guidelines.
- To investigate the global static and dynamic response of the pier system
- Perform comprehensive static and dynamic analyses to understand the overall behavior and stability of the pier system under different loading scenarios.
- To estimate seismic damage and assess structural performance under Zone-V conditions. Evaluate potential damage levels and structural integrity of the pier system when subjected to high-intensity seismic events typical of Zone V regions

II. METHODOLOGY

Geometric Modelling of Precast Concrete Pier Systems for Seismic Zone-V

The first step involves creating geometric models of precast concrete pier systems specifically designed for seismic bridge construction in Seismic Zone-V. The model will focus on defining the overall dimensions of the piers, including the height, cross-sectional shape, and material properties. The model will exclude elements like skew angles, deck slabs, or superstructure components, concentrating solely on the precast pier.

Assign Sectional Properties and Material Properties

Sectional properties such as cross-sectional dimensions of the precast pier will be defined, along with material properties including Young's modulus, Poisson's ratio, and density. These properties will ensure that the pier models accurately reflect the physical characteristics of the materials used in construction, essential for the proper assessment of seismic performance.

Provide Supports: Boundary Conditions

The supports and boundary conditions are then defined to simulate how the precast pier is anchored to its foundation in the real-world scenario. This includes specifying the types of supports (e.g., fixed or pinned) and their locations, which will influence the pier's ability to resist seismic loads and its overall structural behaviour.

Assign Loads & Load Combinations

Various loads, including dead loads, live loads, and seismic loads, are applied to the precast pier models according to the IRC 6:2017 guidelines. The seismic loads will be specifically calculated for Seismic Zone-V conditions, ensuring that the pier design meets the rigorous safety standards for high seismic risk areas. Load combinations are generated to reflect realistic scenarios the pier might encounter during an earthquake.

Analysis

The model is subjected to a comprehensive structural analysis using STAAD Pro or similar software. This analysis will include the calculation of static and dynamic responses such as bending moments, shear forces, deflections, and torsional effects under the applied loads. Seismic analysis will include response spectrum and time-history methods to evaluate the pier's behaviour under seismic forces typical of Zone-V.

Result Comparison

The results from the structural analysis will be compiled and compared to evaluate the performance of the precast pier system. Key parameters such as maximum bending moments, shear forces, deflections, and support reactions will be examined. The analysis will focus on the structural integrity and stability of the pier under the loads defined by IRC 6:2017 and seismic events in Zone-V.

Check for Variations and Design Validation

Finally, variations in the structural responses of the precast pier will be thoroughly examined, particularly under seismic loading. The analysis will assess the pier's resilience under different load combinations, ensuring it meets safety and performance standards. Critical design considerations will be identified, including any adjustments required to optimize the design for rapid construction and enhanced seismic performance.

MODELING AND ANALYSIS

Considerations

- The Circular Precast RCC pier is being considered.
- The pier is solid circular section with pier cap.
- The grade of concrete examined is M35, and the steel used is Fe500.
- The bridge span is 25m + 25m.
- Overall width of bridge deck is 12.50m for 3 lanes.
- The bridge is examined for both dead, live loads, seismic loads and wind load using IRC 6-2017 loading guidelines.
- STAAD Pro software is used to generate and analyze precast pier model.

Loads on pier applied

Dead and Superimposed Loads

Dead loads refer to the gravitational forces caused by the self-weight of the pier structure and any permanently attached elements. These loads are calculated as the product of the volume and density of the material. For the precast concrete pier system, the dead load includes the weight of the pier itself and other permanent elements such as base foundation components. Superimposed loads, on the other hand, represent the gravitational forces from non-structural components like road pavements and other long-term loads that accumulate over the structure's lifespan. These loads are critical in bridge design, especially for long-span structures, as they contribute significantly to the total load on the system. Road pavements, in particular, are subject to increases over time, leading to high load factors applied during the design phase.

Live Loads

Road bridge decks are designed to withstand live loads in accordance with the IRC 6:2017 specifications. The live load typically consists of vehicles, such as those classified under IRC Class A and IRC Class 70R.

IRC Class 70R Loading includes either tracked or wheeled vehicles with specified dimensions (shown in IRC Class 70R guidelines). This type of loading is typically applied for bridges on national highways and is crucial for ensuring that bridges can support heavy vehicles such as trucks and buses. IRC Class A Loading involves a train vehicle comprising a driving vehicle and two trailers with required axle spacing. This load is usually considered in less severe traffic

conditions, such as those on local or regional roads. It is essential to design for both IRC Class A and Class 70R to account for potential higher stress under Class 70R conditions, ensuring the structural integrity of the pier under different vehicle load scenarios.

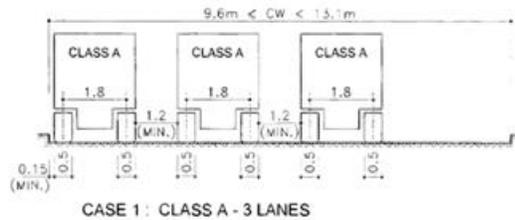


Figure 2: Live Load Case 1

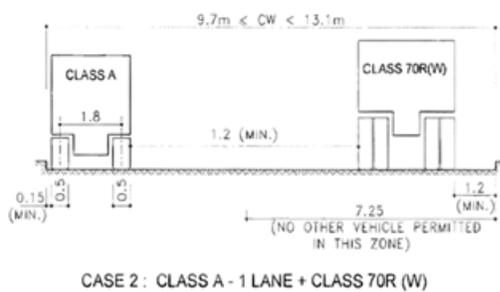


Figure 3: Live Load Case 2

Wind Load

Wind loads are applied to the precast concrete pier system, particularly in regions subject to high wind speeds. The wind load is calculated according to the guidelines in IRC 6:2017, taking into account the location, height of the pier, exposure conditions, and wind speed. Wind forces can have a significant impact on the stability and deflection of the bridge, especially in areas prone to strong winds. The design incorporates these loads to prevent potential instability, ensuring the structure can withstand wind-induced forces.

Seismic Load

Seismic loads are applied to the precast concrete pier system based on the expected ground motion in Seismic Zone-V, the highest seismic risk zone as per IRC 6:2017. Seismic forces are determined by the site’s seismic zone, the type of bridge, and the importance factor. Zone-V conditions involve significant seismic forces, and the design must ensure the pier system can withstand these forces without failure. The seismic load will be applied to evaluate the pier’s behaviour during a potential earthquake, focusing on its ability to absorb energy and maintain integrity.

STAAD Pro Models

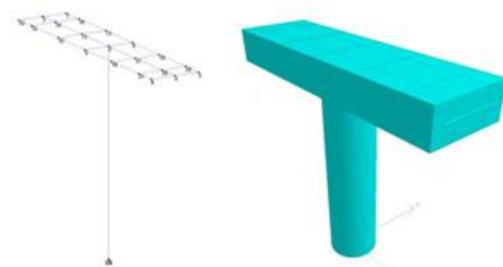


Figure 5: STAAD Pro model of Pier and Pier cap

III. RESULTS AND DISCUSSION

The results obtained from the analysis are presented in terms of critical structural responses, including deflection, longitudinal bending moment, torsional moment, axial load, stresses, and support reactions in Precast Pier models subjected to imposed wheel loads. These structural responses are essential for understanding the behavior and performance of the pier under loading conditions. Deflection indicates the degree of bending in the structure, while the longitudinal bending moment and torsional moment reveal the internal forces along the pier’s length and transverse directions. The axial load reflects the compressive or tensile forces acting along the pier’s axis. Stresses are calculated to assess the material behavior under loading, providing insight into potential failure points or areas of concern. The support reaction helps in understanding how the forces are distributed across the pier’s base. These parameters are integral in designing and ensuring the structural integrity of the pier under traffic loads, helping optimize load-bearing capacity and durability in various operational scenarios.

Summary of loads

Unfactored Loads					
Description of Load	Vertical reactions from the left span				
	1	2	3	4	5
Girder self weight	492	492	492	492	492
SDL reaction	55	55	55	55	55
FPL reaction	0	0	0	0	1
LL reaction left span	89	89	89	89	89
Total	636.8	636.8	636.8	636.8	636.8

Description of Load	Vertical reactions from the right span				
	6	7	8	9	10
Slab	492	492	492	492	492
SDL reaction	55	55	55	55	55
FPL reaction	0	0	0	0	1
LL reaction right span	89	89	89	89	89
Total	636.8	636.8	636.8	636.8	636.8

Factored Loads						Partial Safety factor
Description of Load	Vertical reactions from the left span					
	1	2	3	4	5	
Order self weight	665	665	665	665	665	1.35
SIDL reaction	74	74	74	74	74	1.7
FPIL reaction	0	0	0	0	1	1.15
LL reaction left span	121	121	121	121	121	1.5
Total	860	860	860	860	860	

Description of Load	Vertical reactions from the right span					Partial Safety factor
	6	7	8	9	10	
Slab	664.8	664.8	664.8	664.8	664.8	1.35
SIDL reaction	74.1	74.1	74.1	74.1	93.3	1.7
FPIL reaction	0.0	0.0	0.0	0.0	1.2	1.15
LL reaction right span FP Side	120.8	120.8	120.8	120.8	134.2	1.5
Total	859.7	859.7	859.7	859.7	892.4	

Axial Loads and Moments at the base of Pier Shaft

Summary of Loads and Moments at the Base of Pier Shaft:					
Case No	Case Description	P (kN)	M _L (kN-m)	M _T (kN-m)	M _R (kN-m)
Combination 1					
Case - (i)	Live Load as Leading Load				
a)	Maximum Reaction Case	11157	4782	5272	7117
b)	Maximum Longitudinal Moment Case	10430	4410	3687	5748
c)	Maximum Transverse Moment Case	11086	4846	5755	7524
d)	One Span Dislodged Case	5060	2998	4028	5021
Case - (ii)	Wind Load as Leading Load				
a)	Maximum Reaction Case	10785	1560	5700	5909
b)	Maximum Longitudinal Moment Case	10695	1624	6183	6393
c)	Maximum Transverse Moment Case	10695	1624	6183	6393
d)	One Span Dislodged Case	5365	3622	6524	7462
Combination 2					
Case - (i)	Live Load as Leading Load				
a)	Maximum Reaction Case	7763	1923	633	2025
b)	Maximum Longitudinal Moment Case	7359	1769	83	1771
c)	Maximum Transverse Moment Case	7687	1987	1117	2280
d)	One Span Dislodged Case	4602	2062	283	2081
Case - (ii)	Wind Load as Leading Load				
a)	Maximum Reaction Case	7424	1	-401	401
b)	Maximum Longitudinal Moment Case	7339	64	83	105
c)	Maximum Transverse Moment Case	7339	64	83	105
d)	One Span Dislodged Case	4602	2062	283	2081
Combination 3					
Case - (i)	Longitudinal Seismic Case				
a)	Longitudinal Seismic with Maximum Reaction Case	11325	6193	1962	6496
b)	Longitudinal Seismic with Maximum Longitudinal Case	8736	6193	1953	6493
c)	Longitudinal Seismic with Maximum Transverse Case	8823	6199	1980	6508
d)	Longitudinal Seismic with One Span Dislodged Case	4224	3706	1795	4118
Case - (ii)	Transverse Seismic Case				
a)	Transverse Seismic with Maximum Reaction Case	11325	1865	6603	6862
b)	Transverse Seismic with Maximum Longitudinal Case	8736	1866	6522	6784
c)	Transverse Seismic with Maximum Transverse Case	8823	1872	6550	6812
d)	Transverse Seismic with One Span Dislodged Case	4224	5604	4821	7393

Grade of Concrete	M 35
Permissible Stresses in Concrete for bending Compression	16.80 N/mm ²
Permissible Stresses in Steel for Compression	205 N/mm ²
Permissible Stresses in Steel for Tension	400 N/mm ²
Area of Concrete	3.801 m ²
Area of Steel provided	40212 mm ² OK
Percentage of Steel provided	1.06 %
Area of concrete to resist axial load only	
=	12943110 mm ²
Max Area of Steel = 0.8% of above	103545 mm ²
Min. Area of steel on each f _e 0.0012*Ac	4561.6 mm ² OK
Total Area of vertical reinforcement = 0.0024*Ac	9123 mm ²
= 0.04*Ac	152053 mm ²

Check for Stresses in Pier Shaft after design

Load Case	Load Case No	P (KN)	M _L (KNm)	M _T (KNm)	Stresses ULS		
					σ CONCRETE (N/mm ²)	σ STEEL (N/mm ²)	σ ST COMP (N/mm ²)
Combi - 1							
Case (i) - a)	101	11157	4782	5272	10.30	37.80	59.90
b)	102	10430	4410	3687	8.33	22.04	48.80
c)	103	11086	4846	5755	10.90	45.20	63.30
d)	104	5060	2998	4028	8.50	66.90	48.10
Case (ii) - a)	105	10785	1560	5700	8.60	22.30	50.30
b)	106	10695	1624	6183	9.30	29.40	54.10
c)	107	10695	1624	6183	9.30	29.40	54.10
d)	108	5365	3622	6524	13.70	143.90	75.73
Combi - 2							
Case (i) - a)	109	7763	1923	633	3.70	0.00	22.30
b)	110	7359	1769	83	3.40	0.00	20.40
c)	111	7687	1987	1117	3.90	0.00	23.50
d)	112	4602	2062	283	3.10	4.50	18.30
Case (ii) - a)	113	7424	1	-401	2.20	0.00	13.60
b)	114	7339	64	83	1.90	0.00	12.00
c)	115	7339	64	83	1.90	0.00	12.00
d)	116	4602	2062	283	3.10	4.70	18.30
Combi - 3							
Case (i) - a)	117	11325	6193	1962	9.40	27.30	55.10
b)	118	8736	6193	1953	10.10	52.20	58.20
c)	119	8823	6199	1980	10.10	51.50	58.20
d)	120	4224	3706	1795	7.00	53.50	39.30
Case (ii) - a)	121	11325	1865	6603	10.00	32.60	58.10
b)	122	8736	1866	6522	10.70	59.60	61.50
c)	123	8823	1872	6550	10.70	59.20	61.60
d)	124	4224	5604	4821	14.00	170.50	76.50
					14.00	170.50	76.50
					SAFE	SAFE	SAFE

Maximum stresses does not exceed Permissible Stresses, hence safe.

For Grade of Concrete	M 35
And for Grade of Steel	Fe500D
The permissible stresses are given below :	
Permissible Stresses in Concrete for bending Cor	16.80 N/mm ²
Permissible Stresses in Steel for Tension	400.00 N/mm ²
Permissible Stresses in Steel for Compression	205.00 N/mm ²
Therefore provide 50 Nos. of 32 mm dia bars at equal intervals in pier	

IV. CONCLUSION

The detailed analysis of the Precast Pier subjected to various load cases, including both vertical and horizontal forces, provides a comprehensive understanding of the structural performance. The critical parameters—deflection, bending moments (both longitudinal and torsional), axial loads, and stresses—have been evaluated to ensure the pier

Analysis and Design of section

Analysis of Circular Sections under Axial Load and Bi-Axial Bending moments	
Diameter of Pier section:	2.200 m
Effective Cover	0.075 m
No of bars	50 Nos.
Diameter of bar	0.032 m 32 mm
Code of Practise	IRC
Modular Ratio m	10

performs effectively under the imposed wheel loads and other applied forces.

In terms of stresses, the highest values observed in the concrete for bending compression and the steel reinforcement for both tension and compression are well within the permissible stress limits defined for the materials used. For the concrete of M35 grade, the maximum compressive stress due to bending does not exceed the permissible value of 16.80 N/mm². Similarly, the stresses in the steel reinforcement (Fe500 grade), both in tension (maximum 400 N/mm²) and compression (maximum 205 N/mm²), are also safely below their respective allowable limits. This ensures that the materials will not fail or experience undue deformation under the given loading conditions.

The axial load distribution, which is critical for the overall stability of the pier, is also within the acceptable range. The maximum axial load values computed fall well within the design limits, ensuring that the pier is capable of safely transferring vertical loads without experiencing failure due to buckling or excessive deformation.

From a structural integrity standpoint, the results indicate that the Precast Pier has sufficient strength and stability to carry the imposed loads without risk of failure. The design is considered safe under all the considered load cases, combinations and seismic zone V, as all maximum stresses are within the permissible limits.

Structural Recommendations

To ensure the Precast Pier can reliably support the imposed loads while maintaining safety and durability, it is recommended to provide 50 numbers of 32 mm diameters steel reinforcement bars at equal intervals throughout the pier's length. This reinforcement will provide adequate tensile strength, reduce the likelihood of cracking, and ensure that the pier can handle the applied bending moments and axial forces efficiently.

In conclusion, the pier design, based on the analysis, meets all safety and performance criteria and is deemed structurally sound under the anticipated loading conditions. The recommended reinforcement specifications will help achieve the desired load-carrying capacity and long-term durability, ensuring the pier performs effectively throughout its service life.

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REFERENCES

- [1] Berry, M.P. and M.O. Eberhard, Performance Models for Flexural Damage in Reinforced Concrete Columns (PEER Report 2003/18), Pacific Earthquake Engineering Research Center, University of California, Berkeley, 2004.
- [2] Billington, S.L., R.W. Barnes, and J.E. Breen, Project Summary Report 1410-2F: A Precast Substructure Design for Standard Bridge Systems, Center for Transportation Research, The University of Texas at Austin, 1998.
- [3] Billington, S.L., R.W. Barnes, and J.E. Breen, "A Precast Segmental Substructure System for Standard Bridges," PCI Journal, Vol. 44, No. 4, August 1999, pp. 56-73.
- [4] Hari P. Pokharel, "Seismic Analysis of Precast Segmental Bridge Piers".
- [5] P.B.Raval, "Behavior study of precast pier of bridge for its various shape".
- [6] Kwangmo Lim, Jaeyoon Kang, GumsungRyu, KyungtaekKoh, Kyongchul Kim, "Fundamental Design Concepts of a Modular Pier System Using Ultra-High-Performance Concrete for Solving Construction Errors".
- [7] Billington, S.L. and J.K. Yoon, "Cyclic Response of Unbonded Post-Tensioned Precast Columns with Ductile Fiber-Reinforced Concrete," ASCE Journal of Bridge Engineering, Vol. 9, No. 4, July 2004, pp. 353-363.
- [8] Blakeley, R.W.G. and R. Park, "Seismic Resistance of Prestressed Concrete Beam- Column Assemblies," ACI Journal, Vol. 68, No. 9, September 1971, pp. 677-692.
- [9] Camarillo, H.R., "Evaluation of Shear Strength Methodologies for Reinforced Concrete Columns," Master's Thesis, Department of Civil and Environmental Engineering, University of Washington, 2003.
- [10] Cheok, G.S., W.C. Stone, and S.K. Kunnath, "Seismic Response of Precast Concrete Frames with Hybrid Connections," AC Structural Journal, Vol. 95, No. 5, September/October 1998, pp. 527-539.
- [11] El-Sheikh, M.T., R. Sause, S. Pessiki, and L. Lu, "Seismic Behavior and Design of Unbonded Post-Tensioned Precast Concrete Frames," PCI Journal, Vol. 44, No. 3, May/June 1999, pp. 54-71.
- [12] Jonsson, R., "Direct Displacement Based Design of Seismic Moment Resisting Concrete Frames," Master's Thesis, Department of Civil and Environmental Engineering, University of Washington, 2002.

- [13] Karsan, I.D. and J.O. Jirsa, “Behavior of Concrete Under Compressive Loading,” ASCE Journal of the Structural Division, Vol. 95, No. ST12, December 1969, pp. 2543-2563.
- [14] Kent, D.C. and R. Park, “Flexural Members with Confined Concrete,” ASCE Journal of the Structural Division, Vol. 97, No. ST7, July 1971, pp. 1969-1990.
- [15] Lehman, D.E. and J.P. Moehle, Seismic Performance of Well-Confined Concrete Bridge Columns (PEER Report 1998/01), Pacific Earthquake Engineering Research Center, University of California, Berkeley, 2000.
- [16] Popovics, S., “Numerical Approach to the Complete Stress-Strain Curve of Concrete,” Cement and Concrete Research, Vol. 3, No. 5, September 1973, pp. 583-599.
- [17] IRC:6-2017, “Standard Specifications and Code of Practice for Road Bridges Section: II Loads and Stresses”.
- [18] IRC: 21-2000, “Standard Specifications and Code of Practice for Road Bridges Section: III Cement Concrete (P Reinforced)”.
- [19] IRC: 112-2011, “Standard Specifications and Code of Practice for Concrete Road”
- [20] IS: 456-2000, “Standard Specifications and Code of Practice for Plain and Reinforced Concrete.”
- [21] IRC SP:114-2018, “Guidelines for Seismic Design of Road Bridges”