CONSTRUCTION TECHNOLOGY FOR INTEGRAL BRIDGES WITH BASALT FIBER-REINFORCED POLYMER PRESTRESSING TENDONS

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by

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Department of Civil Engineering

Submitted

in fulfillment of the requirements for the degree of Doctor of Philosophy

to the

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Dedicated to my family members

for their love, support, and inspiration

CERTIFICATE

This is to certify that the PhD thesis titled, "**CONSTRUCTION TECHNOLOGY FOR INTEGRAL BRIDGES WITH BASALT FIBER-REINFORCED POLYMER PRESTRESSING TENDONS**" being submitted by **ALI ALRAIE** to the Indian Institute of Technology (IIT) Delhi for the award of the degree of **DOCTOR OF PHILOSOPHY** is a record of the bonafide research work carried out by him. He worked under my supervision for the submission of this PhD thesis, which to my knowledge has reached the requisite standard as demonstrated by excellent publications in national and international journals.

Further, the contents of his research work, in full or in parts, have not been submitted to any other institute or university for the award of any degree or diploma to the best of my knowledge and belief.

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ABSTRACT

Attention has recently been shifted from the conventional structural materials to advanced composite materials owing to their superior mechanical properties. Basalt fiber-reinforced polymer (BFRP) has been the newest fiber-reinforced polymer (FRP) composite material introduced as reinforcement and prestressing tendons for reinforced concrete (RC) and prestressed concrete (PSC) structures. On the other hand, with the increasing demand on flyovers and bridges in city spaces, planning and design must address faster constructions of aesthetically appealing slender bridges. Hence, joint-less, integral bridges are becoming popular. Therefore, beginning from designing the components required for the use of BFRP in prestressing operations to design procedure of the BFRP-PSC members of integral bridges are required to be developed. Measuring the mechanical properties of BFRP rods/ tendons is challenging using the existing mechanical testing methods due to their relatively lower transverse direction strength. This creates issues not only in characterization of the BFRP in laboratory conditions but also on-field prestressing application in integral bridges. Hence, development of a proper anchor with optimum size for the BFRP rods is crucial for further studies. For this purpose, expansive cement grout-based anchor is developed, tested, and assessed, and the parameters affecting the gripping behavior are studied for optimizing the anchor design based on the finite element (FE) analysis. The proposed anchor is found to have achieved 49% saving as compared to the existing anchor developed by previous researchers. On the other hand, understanding of the thermo-mechanical behavior of the BFRP composites is needed for practical and cost-effective applications in integral bridges, which experience thermal stresses throughout their service lives. Characterization and assessment of performance of the BFRP rods at elevated temperatures is investigated through extensive experimental and analytical studies. Owing to high thermal properties, the BFRP rod could retain 57% tensile strength at 400°C. Consequently, a semi-empirical constitutive law for predicting the thermo-mechanical behavior of FRP composites is proposed and validated with experimental results of research studies from the literature. The proposed model is original, generic, and flexible, and is based on general characteristics of the composite eliminating hence the requirement for conducting the tension test at elevated temperatures.

For addressing the arguable design philosophy of the BFRP-reinforced/ prestressed concrete members, extensive experimental investigations are carried out to assess the flexural performance of the BFRP-prestressed concrete (PSC) beams designed as overreinforced, under-reinforced, and significantly under-reinforced, as well as the non-prestressed concrete beams. The assessment is made based on the flexural strength, serviceability satisfaction, safety factor against failure, and deformability/ ductility. The efficacy of the partial prestressing of the beams in a multi-layered system of tendons is investigated, and an alternative source of ductility is introduced by allowing the tendons to rupture sequentially in a kind of progressive failure. Furthermore, the flexural analysis of the tested beams is carried out based on the available codal provisions and referred studies from the literature for complimenting the experimental findings. Further investigations are carried out on ductility evaluation of concrete beams prestressed with FRP tendons, wherein the effect of the partial prestressing, layering of the tendons, addition of sacrificial rebars, and functionally-graded concrete (FGC) is elaborated. The finite element analysis (FEA) is also employed for further testifying on the efficacy of the introduced techniques in improving the ductility of FRP-prestressed members. The investigations show that the ductile behavior can be achieved in multi-layered systems with energy ratio as high as 82.5%, and in partially prestressed beams with energy ratio above 75%. Apart from that, the natural fiber composites, being cost effective and environmentally friendly, are investigated for possible use in post-tensioning of reinforced concrete beams. The successful utilization of such natural fibers in structural applications may result in more sustainability in construction industry. Finally, to investigate on the efficacy of using BFRP prestressing tendons in integral bridges, BFRP tendons are used for the design of conventional and integral bridges, and a comparative assessment is carried out with steel-prestressed conventional bridges. The integral bridge with BFRP tendons is found to have 71.4% dead weight as compared to the conventional bridge with steel tendons. It is concluded that employing both the techniques of using the non-corroding BFRP tendons and the proposed integral form of bridges is a promising technology in bridge construction.

सार

हाल ही में पारंपरिक संरचनात्मक सामग्रियों से उन्नत मिश्रित सामग्रियों पर उनके बेहतर यांत्रिक गुणों के कारण ध्यान स्थानांतरित कर दिया गया है। बेसाल्ट फाइबर-प्रबलित बहुलक (BFRP) नवीनतम फाइबर-प्रबलित बहुलक (FRP) मिश्रित सामग्री है जिसे प्रबलित कंक्रीट (RC) और प्रेस्ट्रेस्ड कंक्रीट (PSC) संरचनाओं के लिए सुदृढीकरण और प्रेस्ट्रेसिंग पट्टा के रूप में पेश किया गया है। दूसरी ओर, शहर के स्थानों में फ्लाईओवर और पुलों की बढ़ती मांग के साथ, योजना और डिजाइन को सौंदर्य की दृष्टि से आकर्षक पतले पुलों के तेजी से निर्माण को संबोधित करना चाहिए। इसलिए, संयुक्त-विहीन, अभिन्न पुल लोकप्रिय हो रहे हैं। इसलिए, प्रीस्ट्रेसिंग संचालन में BFRP के उपयोग के लिए आवश्यक घटकों को डिजाइन करने से लेकर अभिन्न पुल के BFRP-PSC सदस्यों की डिजाइन प्रक्रिया विकसित करने की आवश्यकता है। BFRP छड़ी / पट्टा के यांत्रिक गुणों को मापना उनके अपेक्षाकृत कम अनुप्रस्थ दिशा शक्ति के कारण मौजूदा यांत्रिक परीक्षण विधियों का उपयोग करना चुनौतीपूर्ण है। यह न केवल प्रयोगशाला स्थितियों में BFRP के लक्षण वर्णन में बल्कि अभिन्न पुलों में साइट पर प्रीस्ट्रेसिंग एप्लिकेशन में भी समस्याएं पैदा करता है। इसलिए, आगे के अध्ययन के लिए BFRP रॉड के लिए इष्टतम आकार के साथ एक उचित धारक का विकास महत्वपूर्ण है। इस प्रयोजन के लिए, विस्तृत सीमेंट ग्राउट-आधारित एंकर विकसित, परीक्षण और मूल्यांकन किया गया है, और परिमित तत्व (FE) विश्लेषण के आधार पर एंकर डिजाइन को अनुकूलित करने के लिए पकड़ बर्ताव को प्रभावित करने वाले मापदंडों का अध्ययन किया गया है। दूसरी ओर, अभिन्न पुलों में व्यावहारिक और लागत प्रभावी अनुप्रयोगों के लिए BFRP संमिश्रित के थर्मो-यांत्रिक व्यवहार की समझ की आवश्यकता होती है, जो अपने पूरे सेवा जीवन में थर्मल तनाव का अनुभव करते हैं। व्यापक प्रयोगात्मक और विश्लेषणात्मक अध्ययनों के माध्यम से ऊंचे तापमान पर BFRP छड़ी के प्रदर्शन की विशेषता और मूल्यांकन की जांच की गई है। नतीजतन, FRP कंपोजिट के थर्मो-यांत्रिक व्यवहार की अनुमान के लिए एक अर्ध-अनुभवजन्य संवैधानिक कानून प्रस्तावित किया गया है और साहित्य से शोध अध्ययन के प्रयोगात्मक परिणामों के साथ सत्यापित किया गया है। प्रस्तावित मॉडल मूल, सामान्य और लचीला है, और समग्र के सामान्य गुणों पर आधारित है, जो ऊंचे तापमान पर तनाव परीक्षण करने की आवश्यकता को समाप्त करता है।

बीएफआरपी-प्रबलित/प्रेस्ट्रेस्ड कंक्रीट सदस्यों के तर्कपूर्ण डिजाइन दर्शन को संबोधित करने के लिए, BFRP-अत्यधिक प्रबलित कंक्रीट बीम तथा BFRP-प्रेस्ट्रेस कंक्रीट (PSC) बीम के फ्लेक्सुरल प्रदर्शन का आकलन करने के लिए व्यापक प्रयोगात्मक जांच की गई, जिसे अत्यधिक प्रबलित, कम-प्रबलित, और अत्यधिक कम-प्रबलित के रूप में डिजाइन किया गया था। यह मूल्यांकन फ्लेक्सुरल ताकत, सेवाक्षमता संतुष्टि, विफलता के खिलाफ सुरक्षा कारक, और विकृति / लचीलापन के आधार पर

किया गया है। टेंडन की एक बहु-स्तरित प्रणाली में बीम के आंशिक प्रेस्ट्रेस की प्रभावशीलता की जांच की गई है, और एक प्रकार की प्रगतिशील विफलता में टेंडन को क्रमिक रूप से टूटने की अनुमति देकर लचीलापन का एक वैकल्पिक स्रोत पेश किया गया है। इसके अलावा, प्रायोगिक निष्कर्षों का समर्थन करने के लिए उपलब्ध कोडल प्रावधानों और साहित्य से अध्ययन के आधार पर फ्लेक्सुरल विश्लेषण किया गया है। FRP टेंडन के साथ प्रेस्ट्रेस कंक्रीट बीम के लचीलापन मूल्यांकन पर आगे की जांच की गई है, जिसमें आंशिक प्रेस्ट्रेसिंग, टेंडन के लेयरिंग, बलि सरिया के अतिरिक्त कार्यात्मक रूप से वर्गीकृत कंक्रीट (FGC) के प्रभाव को विस्तृत किया गया है। परिमित तत्व विश्लेषण (FEA) को FRP-प्रेस्ट्रेस्ड सदस्यों की लचीलापन बढ़ाने में शुरू की गई तकनीकों की प्रभावकारिता का समर्थन करने के लिए भी नियोजित किया गया है। इसके अलावा, प्राकृतिक फाइबर कंपोजिट, लागत प्रभावी और पर्यावरण के अनुकूल होने के कारण, प्रबलित कंक्रीट बीम के पोस्ट-टेंशनिंग में संभावित उपयोग के लिए जांच की गई है। संरचनात्मक अनुप्रयोगों में ऐसे प्राकृतिक रेशों के सफल उपयोग से निर्माण उद्योग में अधिक स्थिरता आ सकती है। अंत में, अभिन्न पुलों में BFRP प्रेस्ट्रेसिंग टेंडन के उपयोग की प्रभावकारिता की जांच करने के लिए, BFRP टेंडन का उपयोग पारंपरिक और अभिन्न पुलों के डिजाइन के लिए किया गया है, और इस्पात-प्रेस्ट्रेस्ड पारंपरिक पुलों के साथ एक तुलनात्मक मूल्यांकन किया गया है। यह निष्कर्ष निकाला गया है कि गैर-संक्षारक BFRP टेंडन और पुलों के प्रस्तावित अभिन्न रूप का उपयोग करने की दोनों तकनीकों का उपयोग पुल निर्माण में एक आशाजनक तकनीक है।

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MATHEMATICAL NOTATIONS

μ_{Ψ}	Curvature-based ductility index
Ψ_u	Curvature at the ultimate moment
Ψ_y	Curvature at the yielding moment
μ_d	Displacement-based ductility index
Δ_u	Displacement at the ultimate load
Δ_y	Displacement at the yielding load
E_{in}	Initial inelastic energy absorbed before reaching the ultimate capacity
$E_{in(addl)}$	Additional inelastic energy absorbed after reaching the ultimate load-carrying capacity
E_{esc}	Elastic energy
T	Pull-out load
U	Circumference of the tendon
L	Length of the anchor
τ_0	Bond stress
μ	Friction coefficient
P	Gripping pressure
σ_r	Radial stress
σ_θ	Hoop stress
σ_z	Longitudinal axial stress
P_i	Internal pressure
P_o	External pressure
r_i	Inner radius of the steel sleeve
r_o	Outer radius of the steel sleeve
r	The radius where the stresses are obtained
$\varepsilon_\theta(r)$	Hoop strain
$u_r(r)$	Radial displacement
$u_{r_i s}(b)$	Radial displacement of the steel sleeve at the grout-sleeve interface
$u_{r_o g}(b)$	Radial displacement of the grout shell at the grout-sleeve interface
$u_{r_i g}(a)$	Radial displacement of the grout shell at the rod-grout interface
$u_{r_o f}(a)$	Radial displacement of the fiber rod at the rod-grout interface

p_{sg}	Internal pressure at the sleeve-grout interface
p_{gf}	Internal pressure at the grout-fiber rod interface
E_f	Transverse elastic modulus of the fiber rod
ν_f	Transverse Poisson's ratio of the fiber rod
P_{grip}	Gripping pressure acting inward on the outer surface of the fiber rod
$P_{\exp}$	Expansive pressure acting outward on the inner surface of the steel sleeve
t_c	Cement grout thickness
$t_{c(opt)}$	Optimal cement grout thickness
L_{grip}	Gripping length
A_v	Volume of anchor
A_l	Length of anchor
f_f	Tensile strength of the fiber rod
d_b	BFRP rod diameter
T_g	Glass transition temperature
σ_A	Stress amplitude
ε_A	Strain amplitude
E^*	Complex modulus
E'	Storage modulus
E''	Loss modulus
δ	Phase angle
T_d	Resin decomposition temperature
f_{uT}	Tensile strength of the BFRP rod at a particular temperature
E_{uT}	Tensile modulus of elasticity of the BFRP rod at a particular temperature
T_0	Room temperature
T_{ref}	Ultimate temperature at which the mechanical properties vanish
$P(T)$	Mechanical properties of the composite at any temperature T
P_0	Mechanical properties of the composite at room temperature
P_r	Mechanical properties of the composite in the decomposed state
v_f	Fiber volume fraction
R^2	Coefficient of determination

f_c'	Compressive strength of concrete
f_t	Tensile strength of concrete
ρ_f	Actual reinforcement ratio
ρ_b	Balanced reinforcement ratio
P_{cr}	Cracking load of the beam
P_u	Load-carrying capacity of the beam
Δ_u	Deflection of the beam at failure
α	Stirrup material factor
β	Failure mode factor
γ	Reinforcement material factor
E_s	Elastic modulus of the steel
f_y	Steel yield strength
f_{ds}	Fiber-reinforced polymer (FRP) design strength
Δf_{es}	Loss due to elastic shortening of concrete
m	Modular ratio
f_{cp}	Compressive stress in the concrete at the tendon level
E_{ci}	Elastic modulus of the concrete at the prestress transfer stage
F_{pi}	Initial prestressing force
e	Eccentricity of the prestressing force
S_b	Section modulus corresponding to the extreme bottom fiber
A	Area of the beam cross-section
M_d	Moment due to dead load
Δf_s	Loss of stress due to shrinkage of concrete
Δf_{cr}	Loss of stress due to creep of the BFRP tendons
f_{pi}	Initial prestress
Δf_r	Loss of stress due to relaxation of the BFRP tendons
f_{ci}'	Compressive strength of the concrete at the prestress transfer
S_t	Section modulus corresponding to the extreme top fiber
β_1	Ratio of depth of the equivalent rectangular stress block to the depth of the neutral axis
f_{fu}	Tensile strength of the BFRP prestressing tendons

ε_{cu}	Ultimate compressive strain in the extreme concrete fiber
ε_{fu}	Ultimate tensile strain of the BFRP
ε_{pmi}	Initial prestressing strain in the lowest prestressing tendon (m^{th} row) farthest from the neutral axis
A_{fi}	Cross-sectional area of the tendon
α_i	Ratio of stress in a tendon at balanced condition to the ultimate tensile strength of the tendon
f_{bi}	Stress in the tendon at the balanced condition
d_m	Distance of the bottommost prestressing tendon (m^{th} row) from the extreme compression fiber
M_{cr}	Cracking moment
f_r	Modulus of rupture of concrete
$\sum \sigma_{bp}$	Resultant compressive stress at the extreme bottom fiber due to prestressing forces
F_{pe}	Magnitude of the total effective prestressing force
e_e	Eccentricity of the total effective prestressing force
n	Depth of neutral axis
f_{pmi}	Initial effective prestress in the bottommost prestressing tendon (m^{th} row)
E_c	Elastic modulus of concrete
A_f	Cross-sectional area of the BFRP tendons
ε_f	Difference between the ultimate rupture strain and the initial prestressing strain of the lowest prestressing tendons
h_i	Distance of the tendons in each individual layer from the extreme compression fiber
ε_{pji}	Initial prestress in a tendon in an individual layer *j*
q	Number of the tendons' layers
d_j	Depth of a prestressing tendon in an individual layer *j* from the extreme compression fiber
h_j	Depth of a non-prestressing tendon in an individual layer *j* from the extreme compression fiber
ε_{pj}	Strain in the prestressing tendons of a layer *j*
ε_{nj}	Strain in the non-prestressing tendons of a layer *j*
ε_c	Strain in the extreme compression fiber of the concrete
C_c	Compressive force resultant in the concrete
F_{pj}	Tensile force in the prestressing tendons placed in a layer *j*
F_{nj}	Tensile force in the non-prestressing tendons placed in a layer *j*
A_{fpj}	Cross-sectional area of prestressing tendons of a layer *j*

A_{fnj}	Cross-sectional area of non-prestressing tendons of a layer *j*
M_u	Moment of resistance
$\bar{d}$	Depth of the centroid of the rectangular stress block of concrete from the top fiber
I_g	Gross moment of inertia of the beam cross-section
I_e	Effective moment of inertia of the beam cross-section
I_{cr}	Moment of inertia of the cracked transformed beam section
M_a	Service load moment at the stage for which the deflection is being considered
β_d	Reduction coefficient related to the reduced tension stiffening exhibited by FRP-reinforced members
M_{dc}	Decompression moment corresponding to zero stress at the extreme bottom fiber
y_g	Uncracked centroidal distance
D	Overall depth of the beam cross-section
y_{cr}	Cracked centroidal distance
G_c	Shear modulus of concrete
F_p	Prestressing force applied at a constant eccentricity
Δ	Beam deflection at the mid-span
x	Shear arm
I_{rep}	Moment of inertia for repeated loading
Δ_r	Residual deflection
d_c	Compressive damage parameter of concrete
d_t	Tensile damage parameter of concrete
σ_{c0}	Yield stress of concrete
ε_{in}	Inelastic strain of concrete
σ_{t0}	Tensile stress of concrete
ε_{cr}	Cracking strain of concrete
ρ_{bs}	Balanced reinforcement ratio corresponding to steel's limit state
ε_y	Yield strain of steel
ρ_{bj}	Balanced reinforcement ratio corresponding to jute's limit state
f_{ju}	Ultimate tensile strength of the jute rope
ε_{ju}	Strain at failure of the jute rope

ε_s	Strain in steel reinforcement
ε_j	Strain in jute rope
d_s	Effective depth of the steel reinforcement
d_j	Effective depth of the natural jute fiber (NJF) rope
ε_{ji}	Initial stress in the NJF rope due to post-tensioning
Ω_u	Ultimate bond reduction coefficient
L_u	Distance between the ends of the post-tensioning rope
T_s	Tensile force in the steel reinforcement
A_s	Area of steel reinforcement
T_j	Tensile force in the natural jute fiber (NJF) rope
E_j	Elastic modulus of the natural jute fiber (NJF) rope
A_j	Cross-sectional area of the natural jute fiber (NJF) rope
k	Wobble coefficient
γ_c	Material partial factor for concrete
γ_s	Material partial factor for steel
φ	Dynamic amplification factor
v	Vehicle speed
R	Radius of curvature of traffic lane
g	Gravity acceleration
P_D	Design wind pressure
P_B	Base wind pressure
V_{DZ}	Design wind velocity at a design elevation Z
V_{10}	Wind velocity at 10 m above water level
V_B	Base wind velocity at 10 m above ground level
Z_0	Friction length of upstream meteorological wind characteristic
Z	Height of structure at which load is being calculated
M_{Ed}	Maximum seismic design moment
M_{Rd}	Section capacity in flexure
C_{sm}	Elastic seismic response coefficient
T	Structural period

A	Acceleration coefficient for the relevant limit state
γ_i	Load factor
ϕ	Resistance factor
R_n	Nominal resistance
R_r	Factored resistance
η	Factor related to ductility, redundancy, and operational importance
η_D	Ductility factor
η_R	Redundancy factor
η_I	Factor related to operational importance
f_{cd}	Design compressive strength of concrete
α_{cc}	Coefficient taking account of long term effects on the compressive strength and of unfavorable effects resulting from the way the load is applied
f_{py}	Yield strength of the prestressing tendon
f_{pu}	Ultimate tensile strength of the prestressing tendon
f_{ss}	Maximum tensile stress in steel reinforcement at service limit state for complying to the crack width maximum value
γ_e	Exposure factor
f_{pu}	Specified tensile strength of prestressed reinforcement (psi)
A_{ps}	Area of prestressed longitudinal tension reinforcement (in.^{2})
f_{se}	Effective stress in prestressed reinforcement (psi)
f_{yt}	Specified yield strength of transverse reinforcement (psi)
A_v	Area of shear reinforcement within spacing *s* (in.^{2})
s	Center-to-center spacing of transverse reinforcement (in.)
A_s	Area on non-prestressed longitudinal tension reinforcement (in.^{2})
f_y	Specified yield strength of non-prestressed reinforcement (psi)
$A_{v,min}$	Minimum area of shear reinforcement within spacing *s* (in.^{2})
λ	Modification factor for lightweight concrete
P_u	Failure load of the beam (lb)
M_{max}	Maximum moment due to failure load (lb·in.)
V_i	Maximum shear force at failure (lb)
V_d	Shear force due to dead load (lb)
f_d	Stress due to dead load, at extreme fiber of section (psi)

f_{pe}	Compressive stress in concrete, due to effective prestressing force, at extreme fiber of section (psi)
f_{pc}	Compressive stress in concrete, due to effective prestressing force, at centroid of cross-section (psi)
M_{cre}	Moment causing flexural cracking due to applied loads (lb·in.)
V_{ci}	Nominal shear strength provided by concrete where diagonal cracking results from combined shear and moment (lb)
V_{cw}	Nominal shear strength provided by concrete where diagonal cracking results from high principal tensile stress in web (lb)
V_c	Nominal shear strength provided by concrete (lb)
V_s	Nominal shear strength provided by shear reinforcement (lb)
V_n	Nominal shear capacity of beam section (lb)

ABBREVIATIONS

RC	Reinforced Concrete
PSC	Prestressed Concrete
FRP	Fiber-Reinforced Polymer
BFRP	Basalt Fiber-Reinforced Polymer
GFRP	Glass Fiber-Reinforced Polymer
CFRP	Carbon Fiber-Reinforced Polymer
TBM	Tunnel Boring Machine
CFCC	Carbon Fiber Composite Cables
ACI	American Concrete Institute
AFRP	Aramid Fiber-Reinforced Polymer
AASHTO	American Association of State Highway and Transportation Officials
FRC	Fiber-Reinforced Concrete
NSC	Normal Strength Concrete
HSC	High-Strength Concrete
CFRC	Coconut Fiber-Reinforced Concrete
JFRCC	Jute Fiber-Reinforced Cementitious Composite
FFRP	Flax Fabric-Reinforced Polymer
SCM	Supplementary Cementitious Material
FEA	Finite Element Analysis
FGC	Functionally-Graded Concrete
JSCE	Japan Society of Civil Engineers
ASCE	American Society of Civil Engineers
CDP	Concrete Damaged Plasticity
UTM	Universal Testing Machine
SEM	Scanning Electron Microscopy
DMTA	Dynamic Mechanical Thermal Analysis
TGA	Thermo-Gravimetric Analysis
RRC	Remaining Resin Content
IS	Indian Standard

OPC	Ordinary Portland Cement
SSD	Saturated-Surface-Dry
LVDT	Linear Variable Differential Transformer
NJF	Natural Jute Fiber
SSB	Simply-Supported Bridge
IAB	Integral Abutment Bridge
SV	Special Vehicle
CQC	Complete Quadratic Combination
BS	British Standards
SIDL	Superimposed Dead Load
SRSS	Square Root of the Sum of Squares
ADTT	Average Daily Truck Traffic
ADTTSL	Average Daily Truck Traffic for Single-Lane
ULS	Ultimate Limit State
SLS	Serviceability Limit State
DL	Dead Load
LL	Live Load
WL	Wind Load
EQ	Earthquake
RCC	Reinforced Cementitious Concrete