IOWA STATE UINVERSITY

Department of Civil, Construction and Environmental Engineering

MIDAS Expert Webinar

Estimating Column Design Forces in Post-Tensioned Box Girder Bridges with Consideration to Time Dependent Effects

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Project Details

- Sponsor: California Department Transportation
- Project Manager: Dr. Charles Sikorsky, Caltrans
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Outline

- Background
- Problem Statement
- Research Goals
- Time-dependent Effects on Posttensioned Concrete Box-girder Bridges
- Conclusions

Background

Why Prestress?

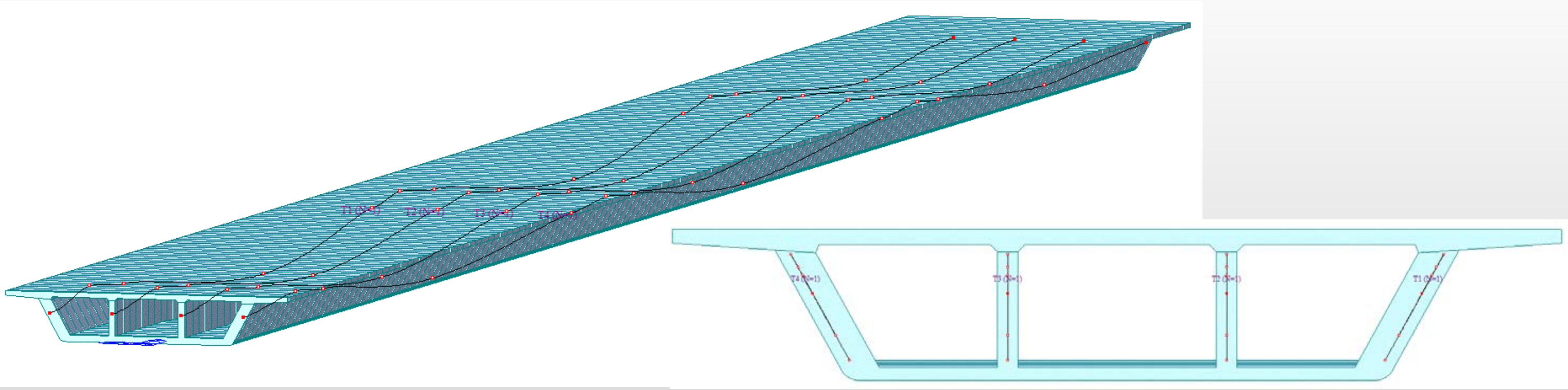
- To counteract high internal forces and stresses expected due to dead and live loads
- It can also minimize deflections and improve shear behavior.

Effects of Prestressing

- Concrete – subjected to compression and tension
- Prestressing tendons - subjected to tension

Method of Prestressing

- **Post-tensioning** - tendons are stretched after casting and curing of concrete



A box-girder as the posttensioned beam

Background

TIME-DEPENDENT EFFECTS ON PRESTRESSED BRIDGES

- Strains and stresses in a prestressed concrete bridge continuously change over a long period of time due to:

Time-Dependent Properties of Concrete and Steel

- Concrete creep and shrinkage
- Concrete relaxation
- Relaxation of prestressing steel
- Prestress losses

Thermal Effects

- Heat gain and loss due to solar radiation and convection to or from the surrounding atmosphere

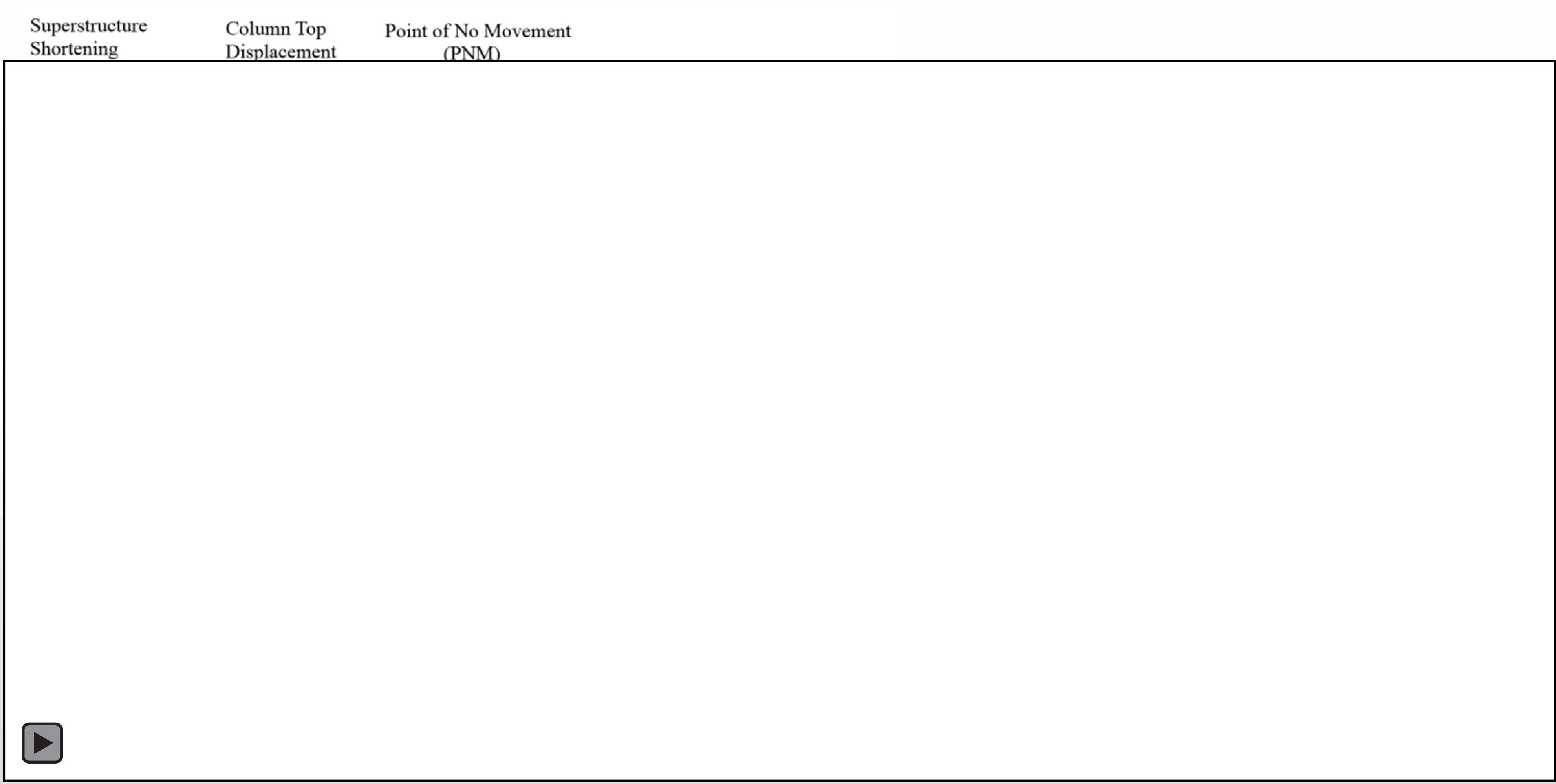
Variation in Loading and/or Support Locations

- Different construction stages of a prestresed bridge

Inefficient and inaccurate design of prestressed bridges may be possible due to complexity and interdependency of the time-dependent effects

Problem Statement

As the superstructure shortens with time due to creep and shrinkage, columns are displaced laterally resulting in the induced forces/stresses in the columns



Problem Statement

Concerns with the Current Design Practice

- Use of a constant strain rate may not be appropriate
- All columns might not experience cracking
- Ignoring/inaccurately modelling the beneficial effects of concrete relaxation

Consequences

- Overestimation of column base shear force
- Inefficient design of columns and foundation, increase in the adverse effects of time-dependent issues, and thus increased construction costs

Note: Although not studied herein, the thermal effects also cause movement of the superstructure, which should also be adequately addressed

Research Objectives

- Improve the prediction of the strain and stress build-up during and after construction
- Reduce construction challenges and associated costs due to the inaccurate design

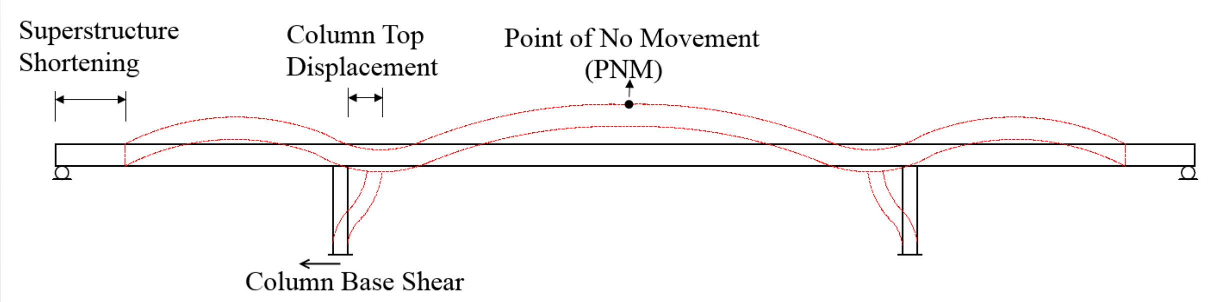
The research objectives were achieved by

- Improving the prediction of time-dependent effects on CIP/PCBB systematically

Time-Dependent Effects on PCBB

Current Design Practice and Concerns

- Shortening strain rate of 525 με for the superstructure → Originally established for joint bearing design
- Calculate the point of no movement (PNM) on superstructure
- Calculate the column lateral top displacement
- Calculate the column base shear force as the product of column displacement and stiffness with consideration to the possible column cracking → Ignoring concrete relaxation and assuming all columns crack



Time-Dependent Effects on PCBB

What is new in this investigation

- Quantifying the relaxation of normal strength concrete
- Examining the beneficial effects of concrete relaxation on a prototype CIP/PBB
- Investigating the time-dependent effects on eight different CIP/PCBB using the FEA
- Developing simplified but rational design recommendations

Time-Dependent Effects on PCBB

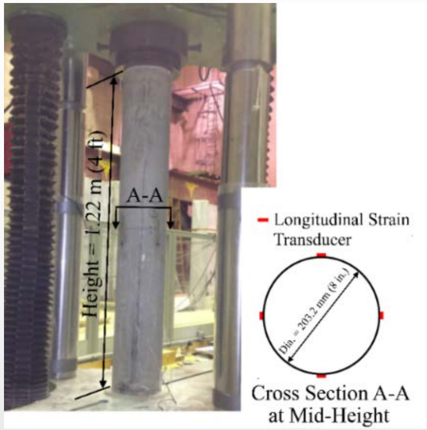
Relaxation Tests

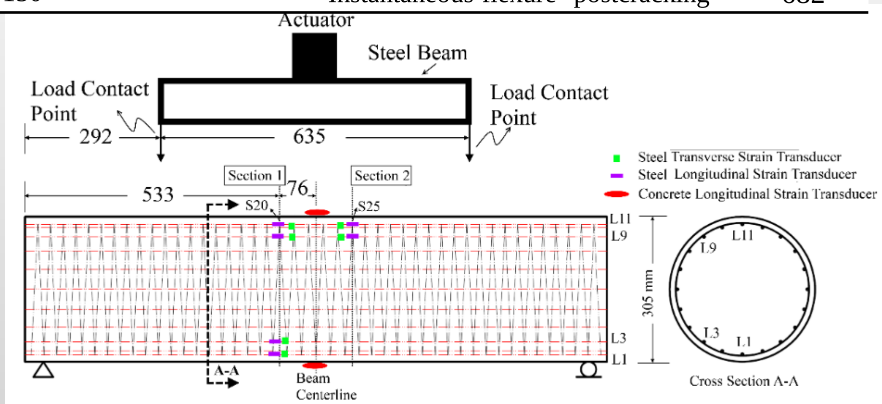
Descriptions of the specimens used for the relaxation tests

Specimen number	Type	Diameter	Length	Loading ages (day)
1	Circular concrete column	203.2 mm (8 in.)	1.22 m (4 ft)	48, 76, 78, 84
2	Circular concrete column	304.8 mm (12 in.)	1.22 m (4 ft)	67
3	Circular RC beam	203.2 mm (8 in.)	1.22 m (4 ft)	130, 150

Details of the seven relaxation tests

Test Number	Specimen used	Specimen age at loading (day)	Test duration (hours)	Loading type	Initial strain (με)
1	1	48	109	Instantaneous axial compression	422
2	2	67	112	Instantaneous axial compression	452
3	1	76	73	Instantaneous axial compression	435
4	1	78	116	Incremental axial compression	43*
5	1	84	90	Incremental axial compression	87*
6	3	130	119	Instantaneous flexure- precracking	198
7	3	150	120	Instantaneous flexure- postcracking	682





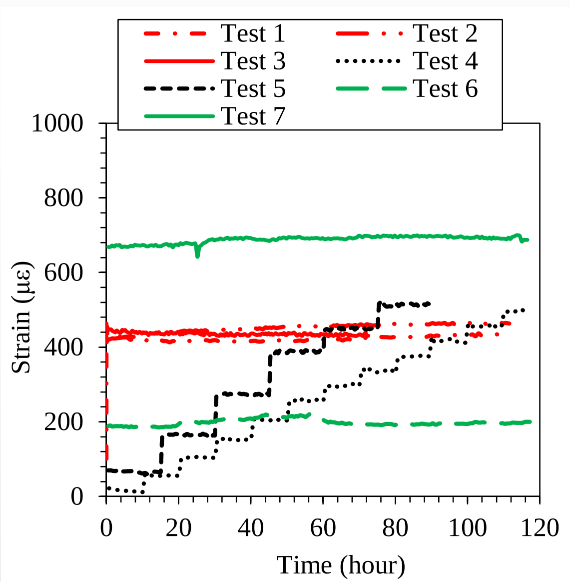
Time-Dependent Effects on PCBB

Observed Behavior

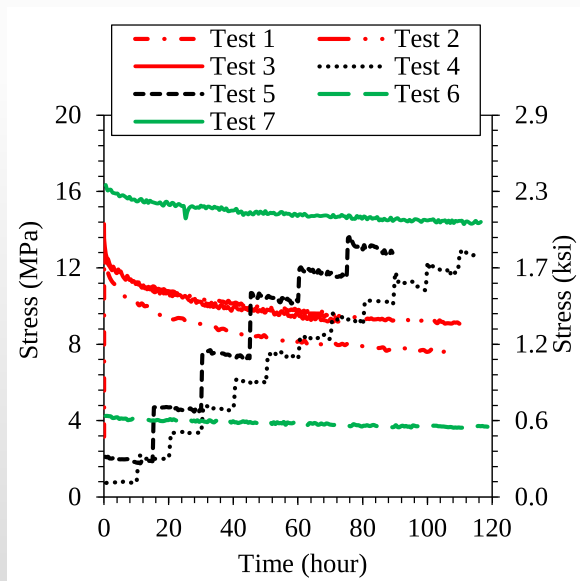
- Reduction in concrete forces/stresses with time under the state of the constant strain for the seven tests.

Results of the seven relaxation tests

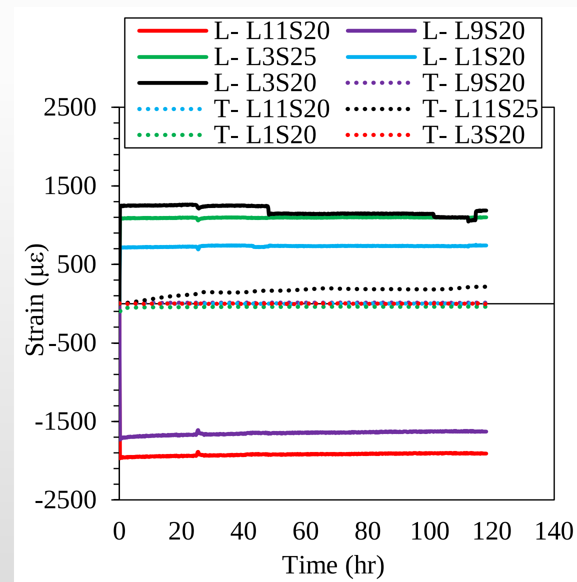
Test	Variation in mean applied strain (με)	Thermal and shrinkage strains (με)	Stress (MPa)		Stress relaxation (%)
			Start	End	
1	±6	< 10	13.7	7.0	49
2	±11	< 10	13.9	9.0	35
3	±22	< 10	14.3	8.7	39
4	±5	< 10	15.2	11.9	22
5	±4	< 10	15.0	11.9	21
6	±10	< 10	4.6	3.7	21
7	±57	< 10	17.2	14.5	16



Variation of concrete strain with time



Variation of concrete stress with time



Variation of steel strain with time for Test 7

Time-Dependent Effects on PCBB

Relaxation Functions

- The reduction in the stress due to a unit constant strain
- Using the AASHTO recommended creep model, the relaxation functions were estimated based on the following equations:

<u>Exact solution using the finite-element model (FEM)</u>

$$\Delta R(t_i) = -\frac{\sum_{i=1}^{k}[J(t_k, t_i) + J(t_k, t_{i-1}) - J(t_{k-1}, t_i) - J(t_{k-1}, t_{i-1})]\Delta R(t_i)}{J(t_k, t_k) + J(t_k, t_{k-1})}$$

<u>Approximate method proposed by Bazant</u>

$$R(t, t_0) = \frac{1 - \Delta_0}{J(t, t_0)} - \frac{0.115}{J(t, t-1)}\left[\frac{J(t_0 + \xi, t_0)}{J(t, t-\xi)} - 1\right]$$

$$\xi = \frac{1}{2}(t - t_0$$

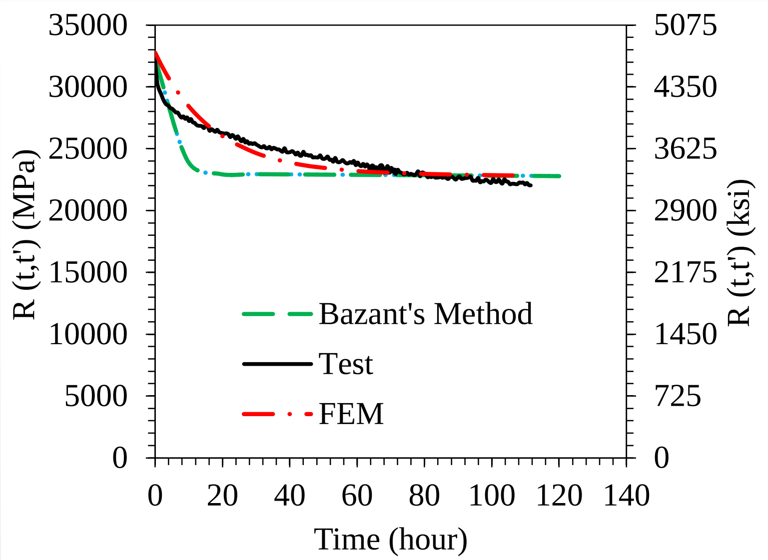
<u>Simplified analysis (stress remains constant over time)</u>

$$R(t, t_0) = \frac{1}{J(t, t_0)}$$

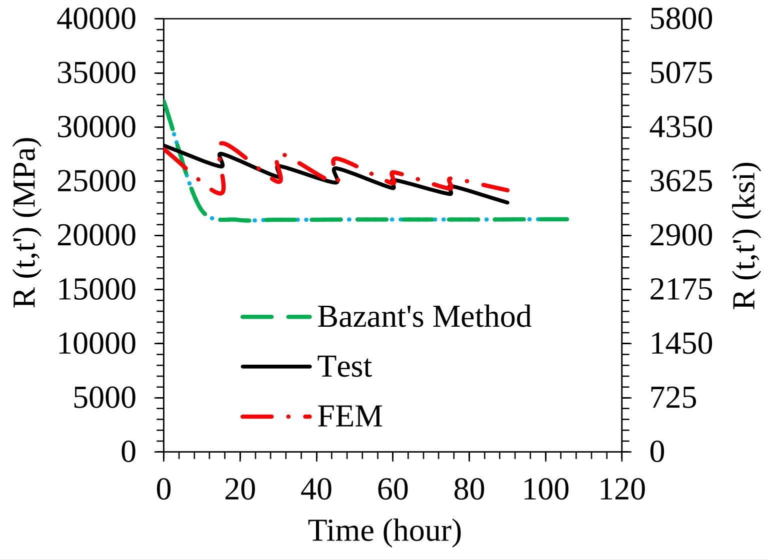
Time-Dependent Effects on PCBB

Relaxation Functions

- A good agreement between the test and the FEM results
- Identical approximation of the relaxation functions by the simplified analysis and the Bazant's method



Test 2



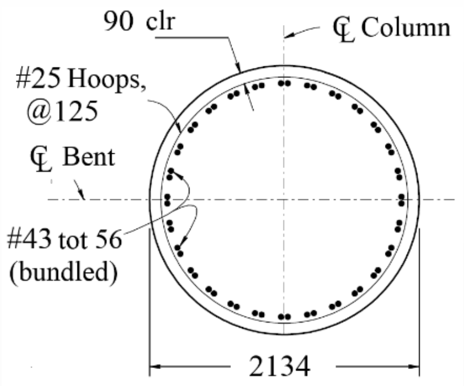
Test 5

Concrete relaxation functions calculated using the different methods

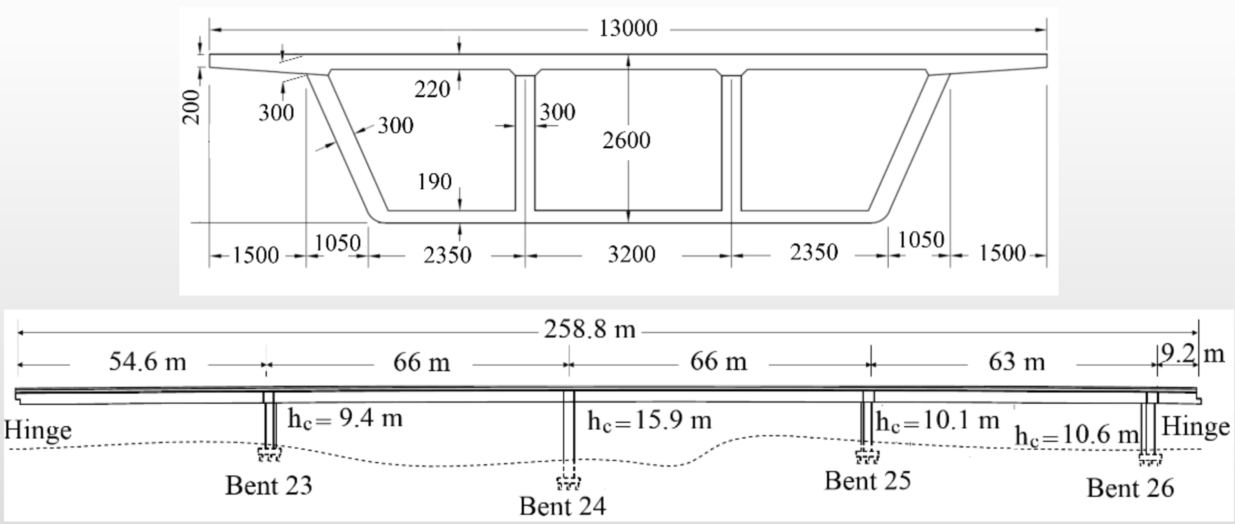
Time-Dependent Effects on PCBB

Beneficial Effects of Concrete Relaxation on a CIP/PCBB

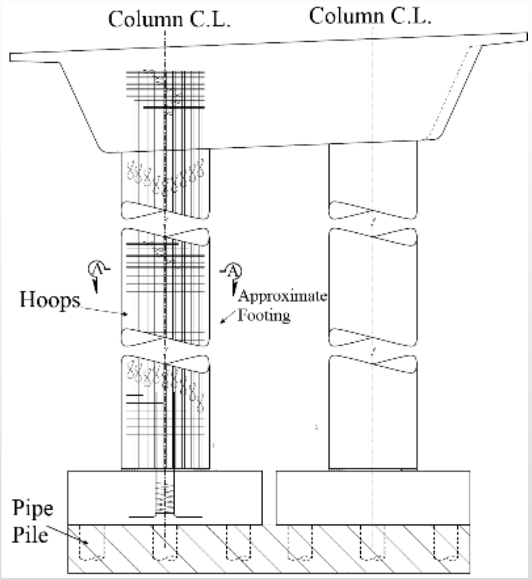
- Frame 6 of the *Floodway Viaduct Bridge* was modeled in *midas Civil Software* to examine the time-dependent effects on a CIP/PCBB with due consideration to the relaxation of concrete columns



Section A-A



Elevation view and box-girder cross section



Bent details

Time-Dependent Effects on PCBB

Finite-Element Analysis (FEA)

Model Assumptions

- Zero curvature
- Disregarding non-prestressed reinforcement
- Linear elastic behavior for columns

Material Models

Material property	Model	
	Box-girder	**Column**
Variation in concrete compressive strength with time	ACI	Not Applicable
Modulus of elasticity	AASHTO	AASHTO
Concrete creep/relaxation	AASHTO	AASHTO
Concrete shrinkage	AASHTO	AASHTO
Relaxation of posttensioned tendons	AASHTO	Not Applicable

Loading

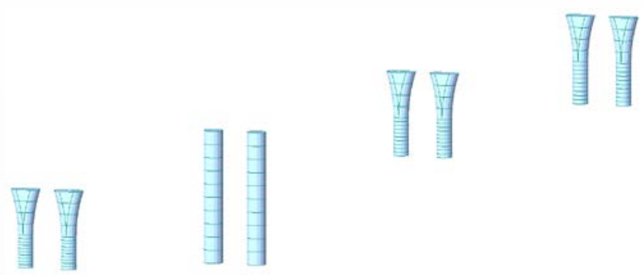
- Only dead load and prestressing force

Column Stiffness

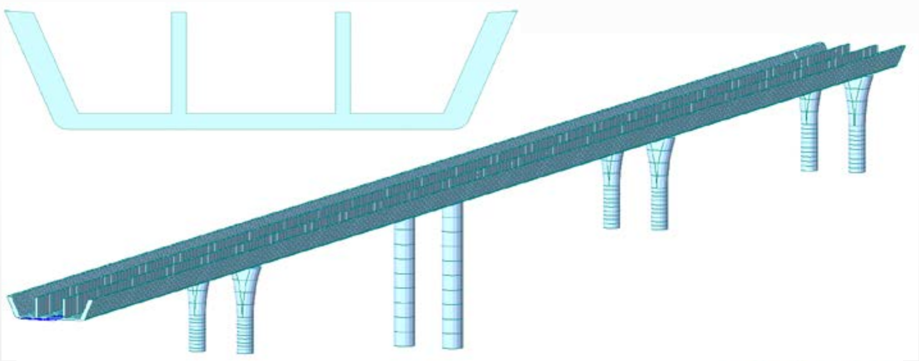
- Moment-curvature analysis using *XSection*

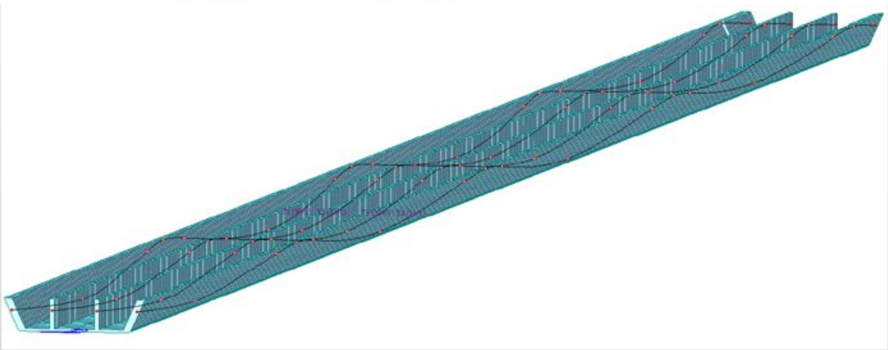
Construction Stages Sequence

Time-Dependent Effects on PCBB



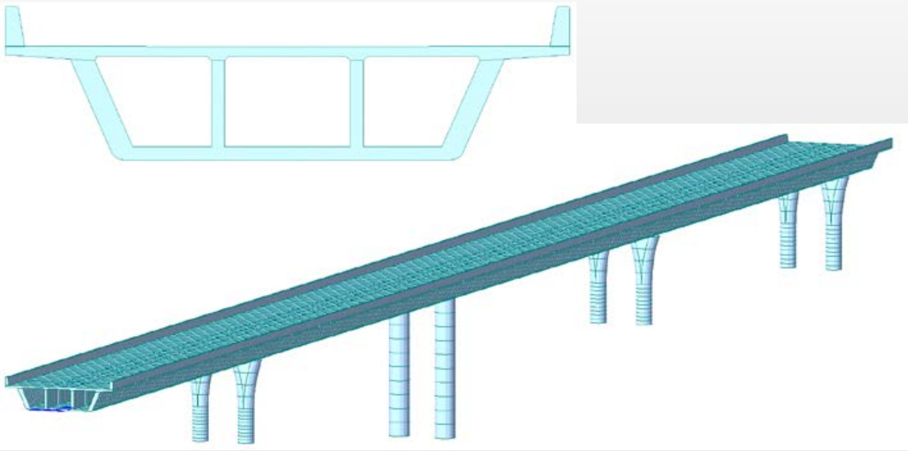
1- Piers construction (t= 0-90 days)





2- Box-girder construction (t= 90-180 days)

3- Deck construction (t= 180-210 days), followed by prestressing (t= 210-220 days)

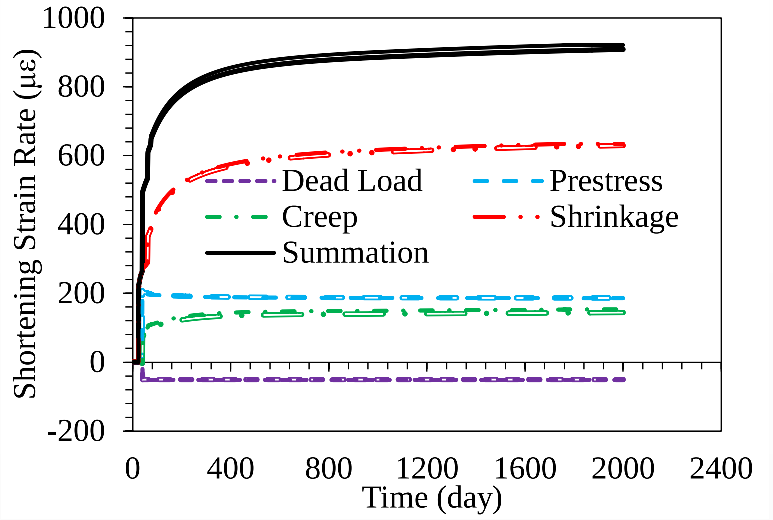


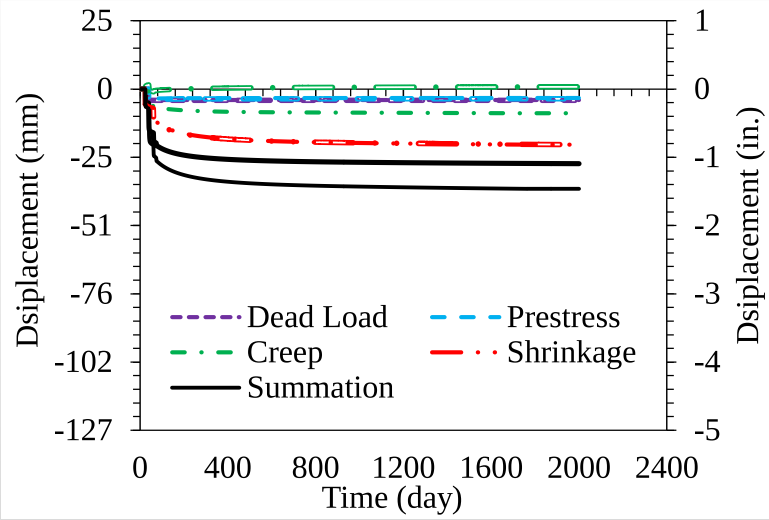
4- Barriers construction (t= 220-235 days)

Time-Dependent Effects on PCBB

Results

- With and without column relaxation
- Shortening strain rate of superstructure
- Variation of column lateral top displacement with time
- Variation of column base shear force with time





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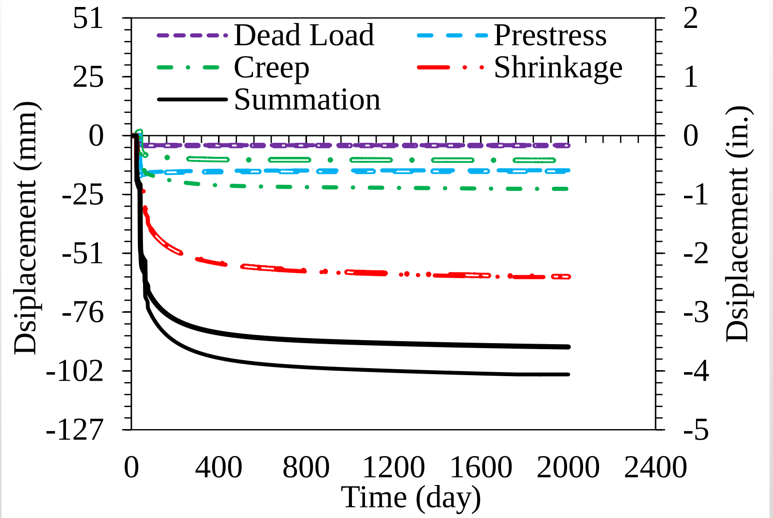

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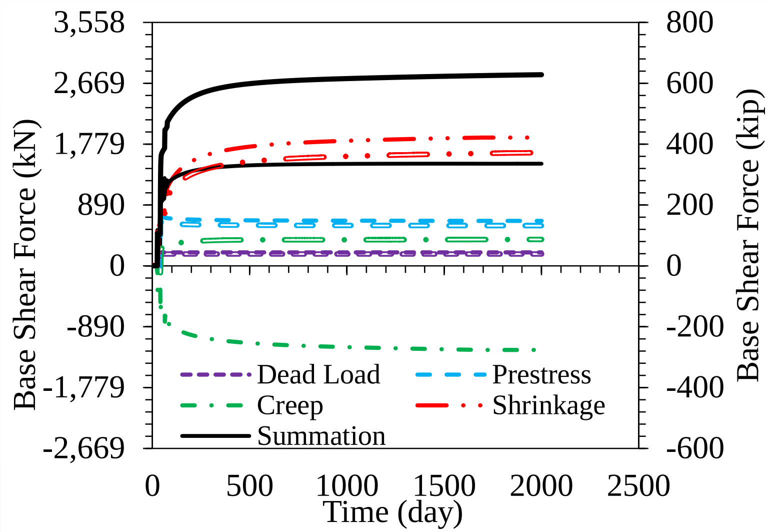
Time-Dependent Effects on PCBB



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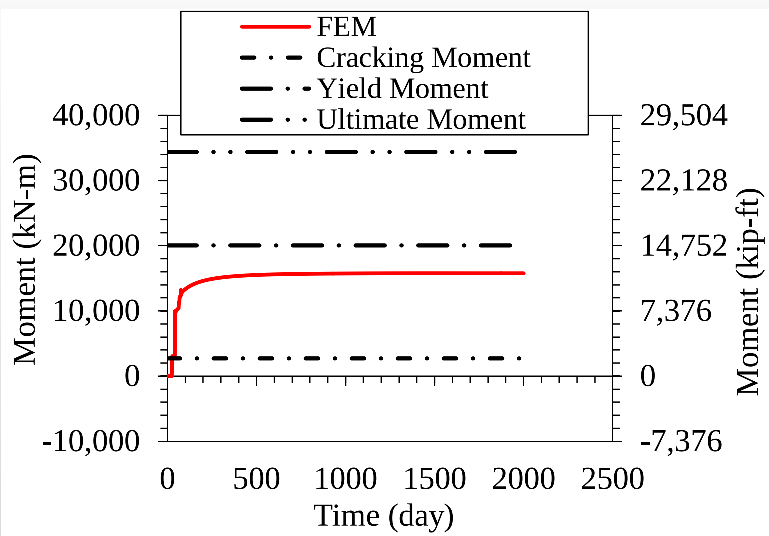

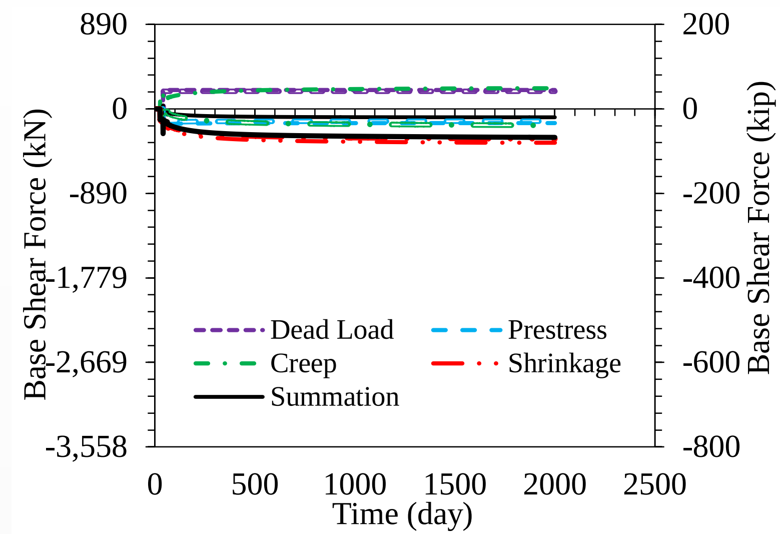

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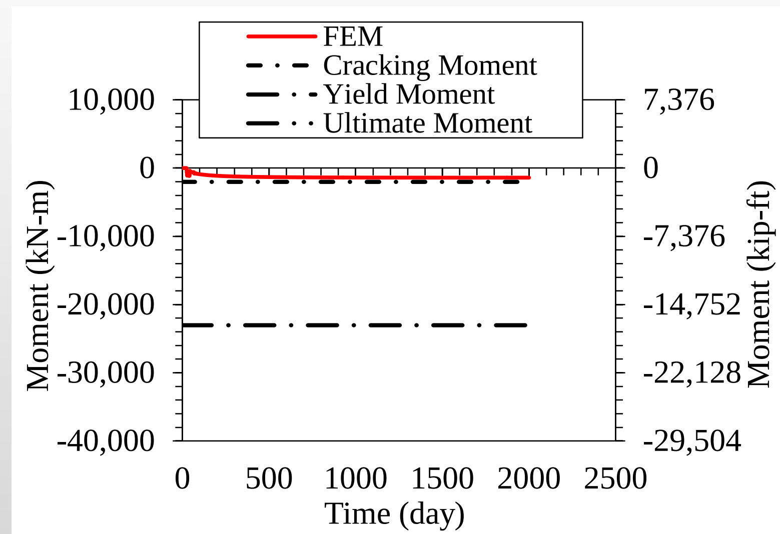
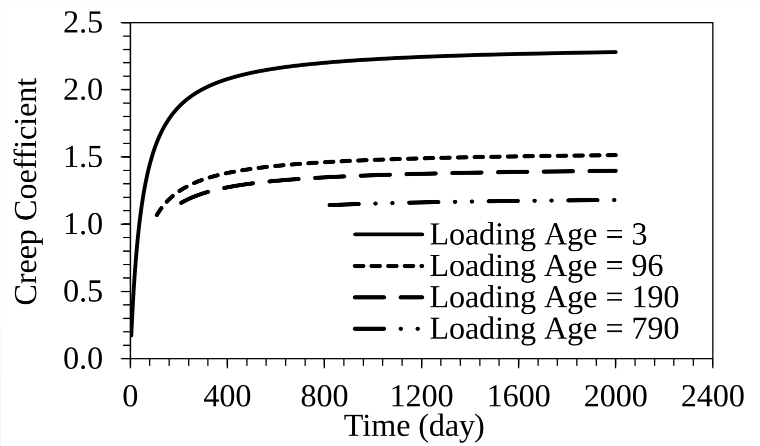
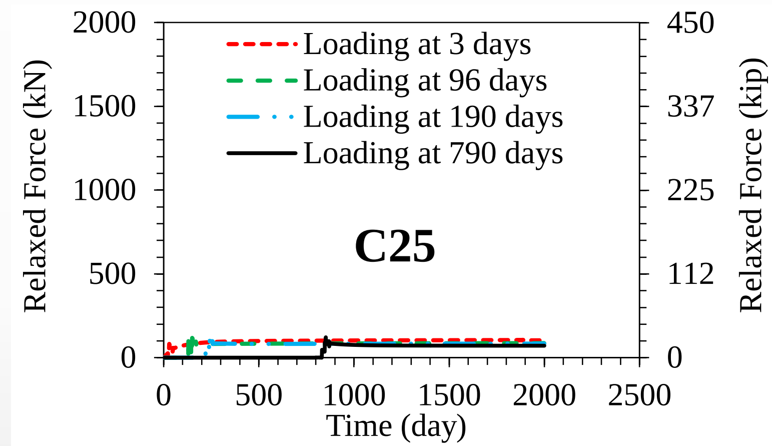


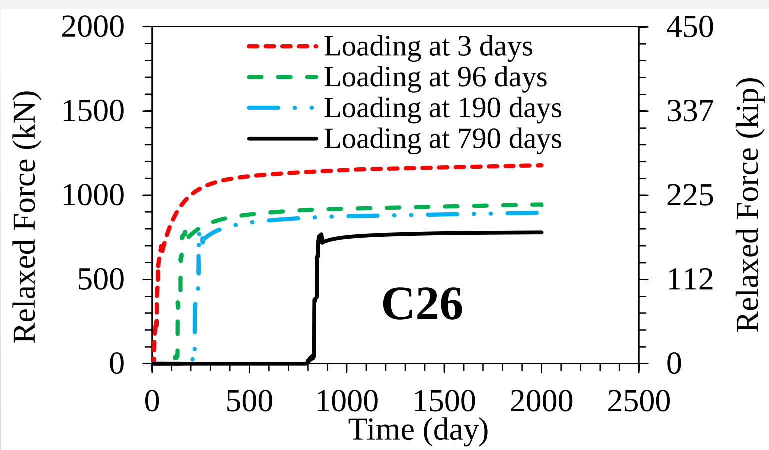
Time-Dependent Effects on PCBB

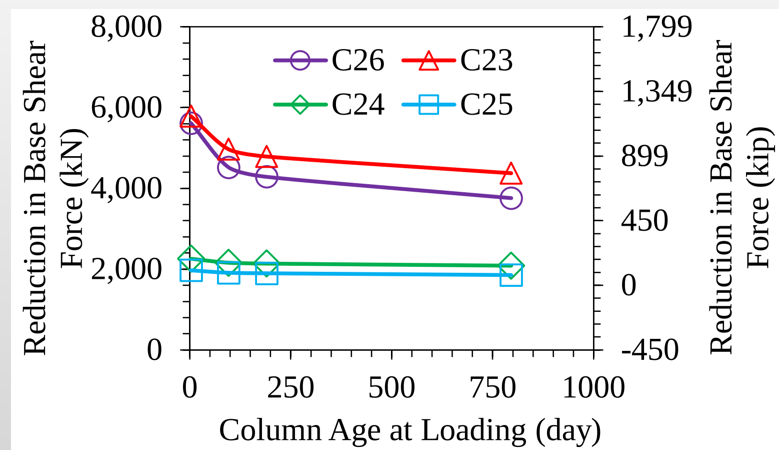
Effects of Loading Age

- The AASHTO creep coefficient
- Relaxed forces for the loading ages of three, 96, 190, and 796 days









Time-Dependent Effects on PCBB

Time-Dependent Effects On Eight Different PCBBs Using the FEA

- Descriptions of eight different PCBBs of various span lengths and configurations
- Calculation of the shortening strain rate of superstructure
- Calculation of column lateral top displacement and the corresponding base shear force
- Evaluate the current design practice against the FEA results
- Develop simplified but rational design recommendations

Time-Dependent Effects on PCBB

Descriptions of PCBBs

- Small-, short-, and long-span bridges
- Pier type, multiple vs. single column bents,
- Connection type to foundation
- Box-girder prestressing details

Bridge and column nomenclatures

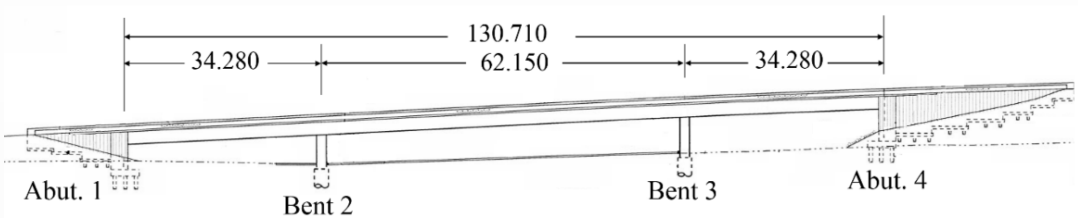
Type	Bridge	Bridge label	Bridge length (m)	Column label
Short	WB SR60 HOV Connector	B1	145.4	B1-Ci; where i=2:3
	Floodway Viaduct-Frame 8	B2	131.0	B2-Ci; where i=31:33
Medium	S405-E22 Connector	B3	293.4	B3-Ci; where i=2:3
	Floodway Viaduct -Frame 6	B4	258.8	B4-Ci; where i=23:26
	Estrella River	B5	231.3	B5-Ci; where i=2:6
Long	N805-N5 Truck Connector	B6	358.0	B6-Ci; where i=2:8
	Santiago Creek	B7	387.3	B7-Ci; where i=2:6
	Trabuco Creek	B8	426.7	B8-Ci; where i=2:8

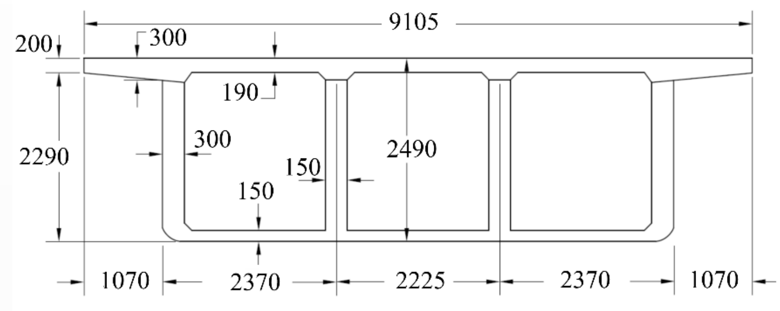
Details of the box-girder prestressing

Bridge name	P_{jack} (kN)	Initial axial stress (MPa)	Anchorage set (mm)	Friction coefficient, μ	Wobble coefficient, κ (1/mm)
B1	36700	6.7	10	0.15	6.60E-07
B2	32199	4.8	10	0.2	6.56E-07
B3	131928	11.4	10	0.2	6.56E-07
B4	49199	6.8	10	0.2	6.56E-07
B5	52042	5.9	10	N.A*.	N.A*.
B6	41059	6.2	10	N.A*.	N.A*.
B7	17298	6.8	0	0.2	0.00E+00
B8	63099	7.4	10	0.25	1.48E-06

Time-Dependent Effects on PCBB

Bridge Elevation Views and Cross Sections





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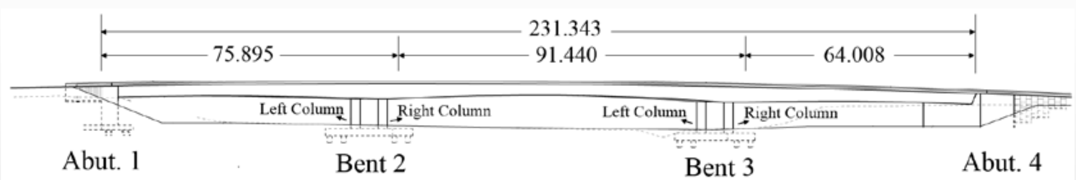

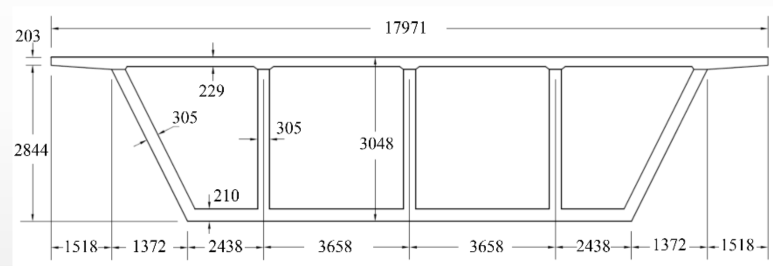

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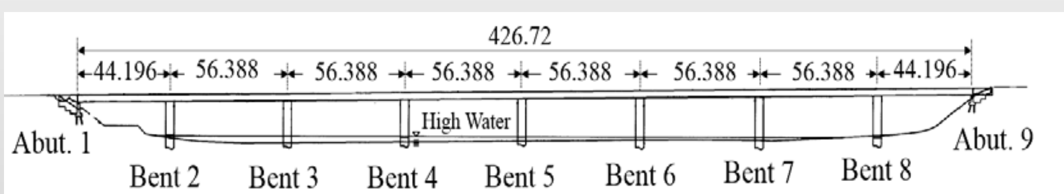

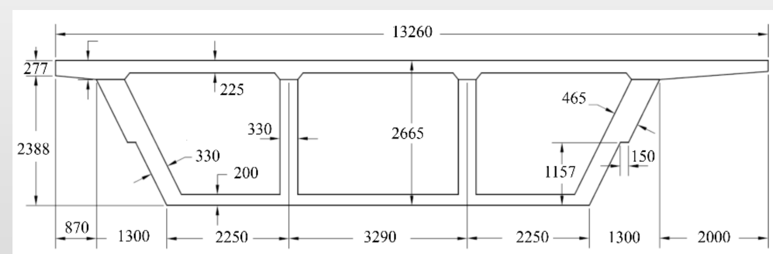

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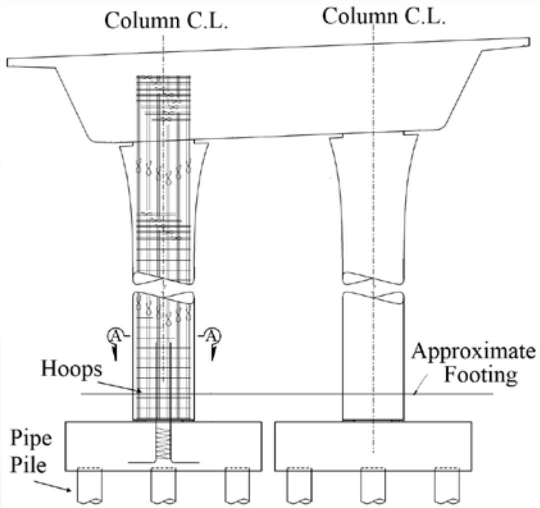
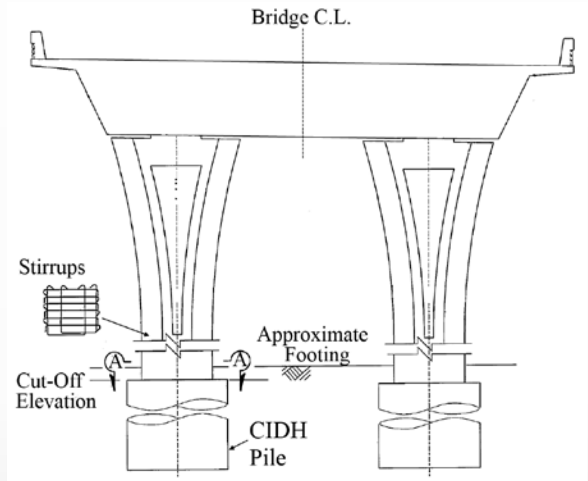
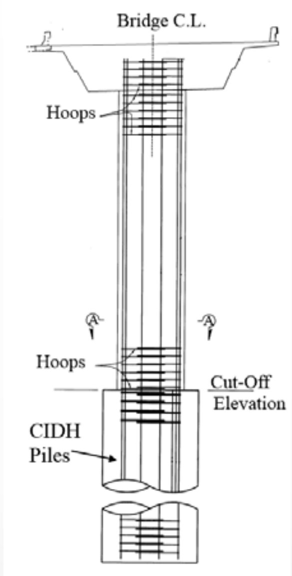
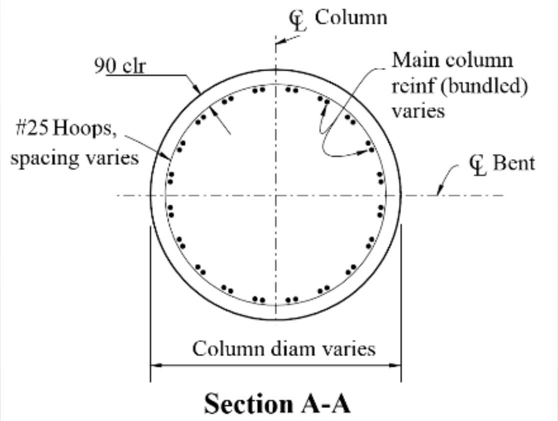
Time-Dependent Effects on PCBB

Bridge Bent Details









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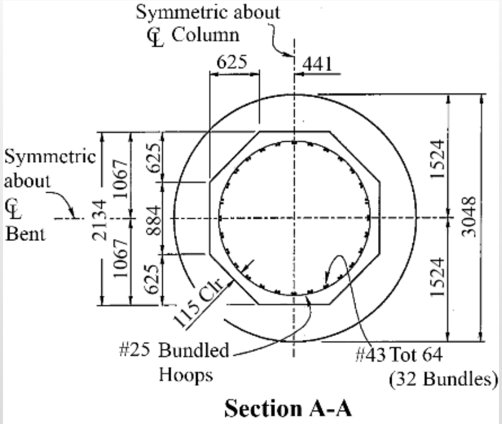

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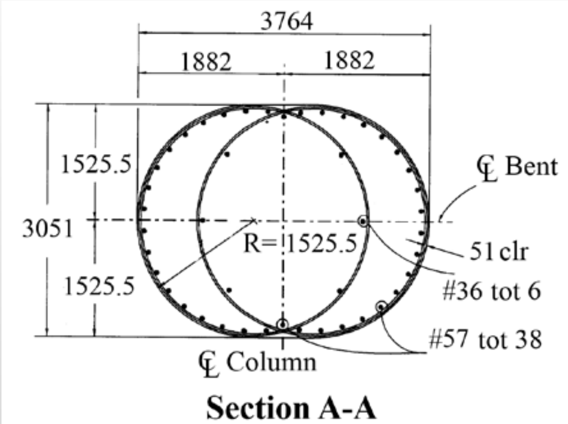

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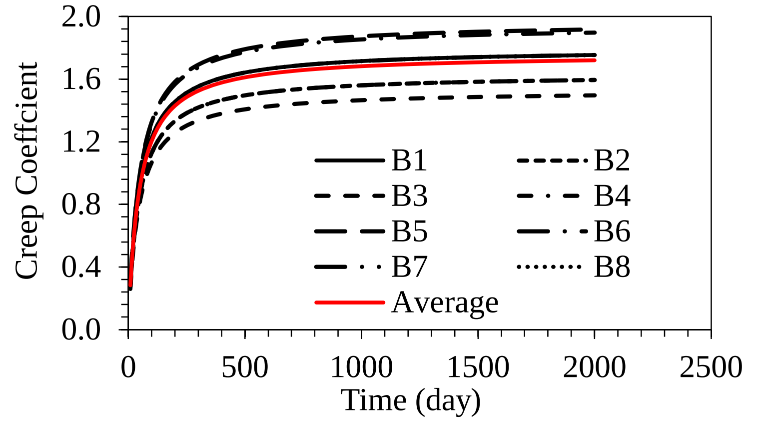
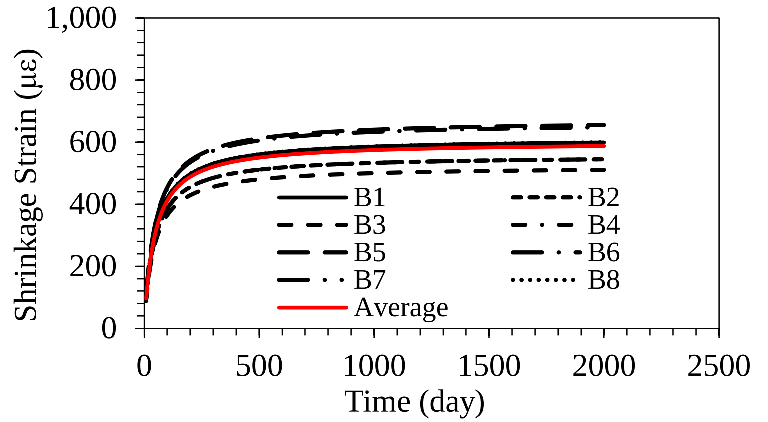
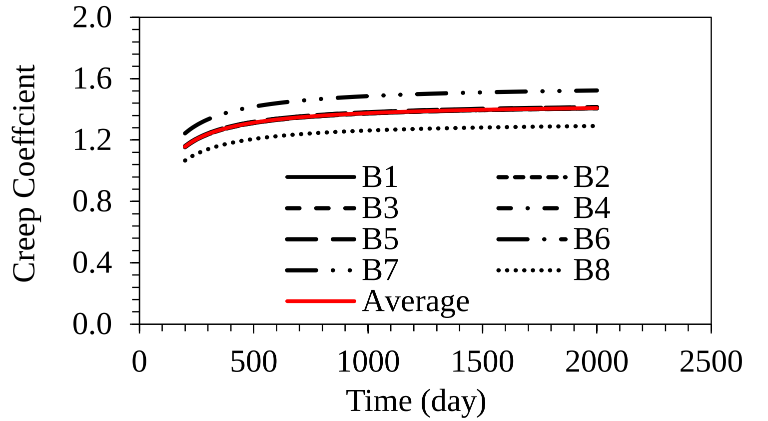
Time-Dependent Effects on PCBB

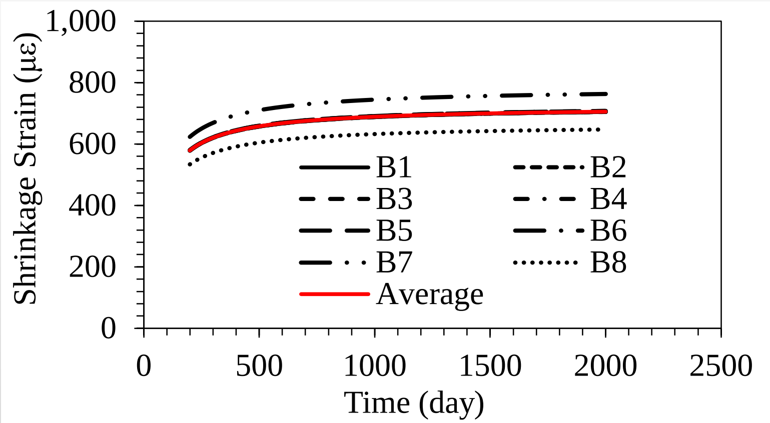
AASHTO Creep Coefficients and Shrinkage Strains for the Eight PCBBs





box-girders



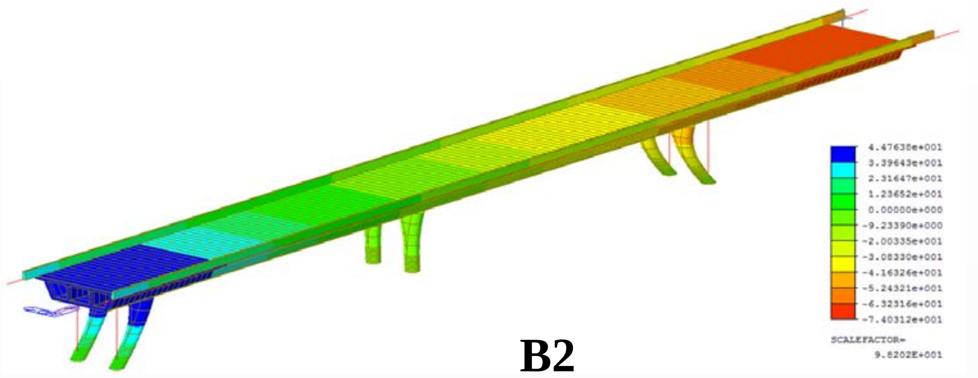


Columns

Time-Dependent Effects on PCBB

Results

- Shortening strain rate of the superstructure due to dead load, prestress, creep, and shrinkage
- Variation of column lateral top displacement and the corresponding base shear force with time



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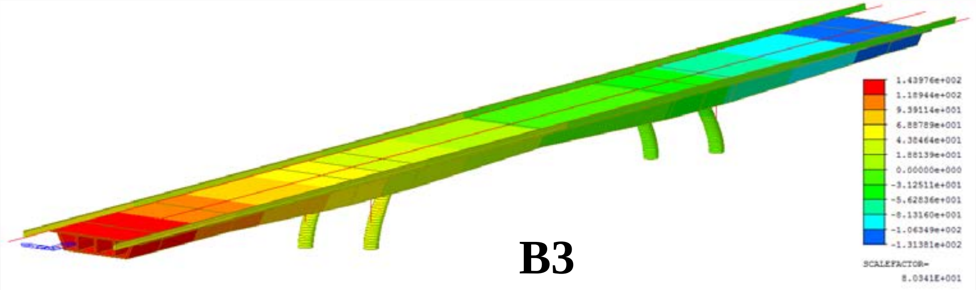

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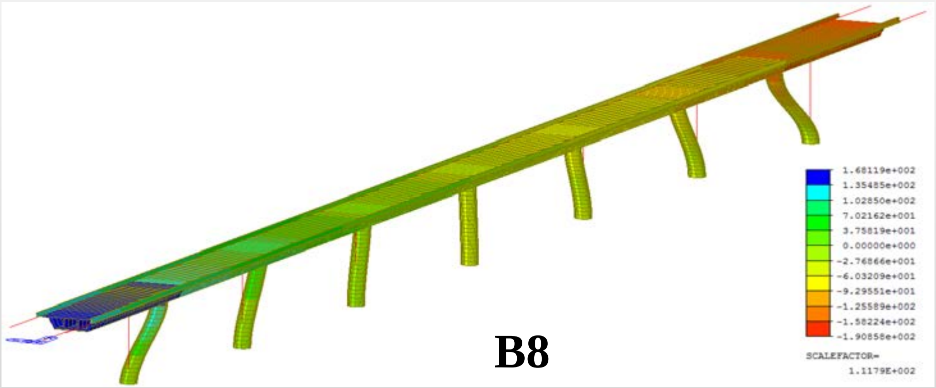

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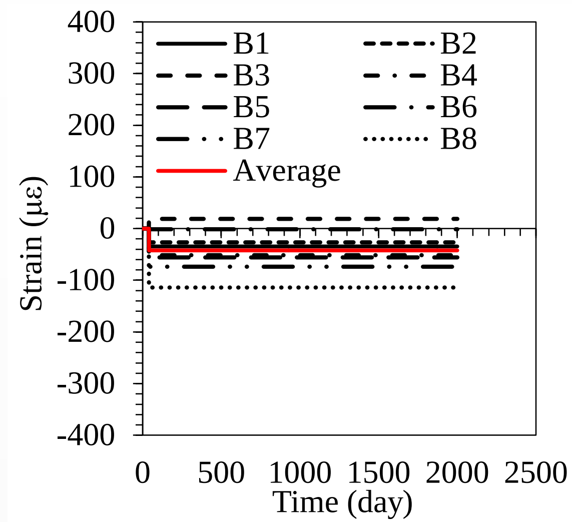
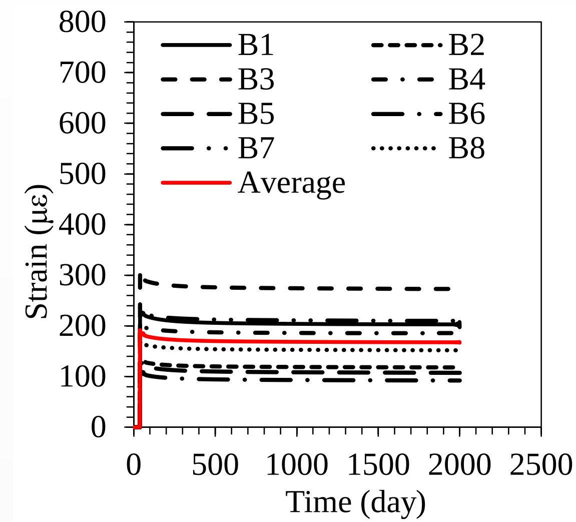
Time-Dependent Effects on PCBB

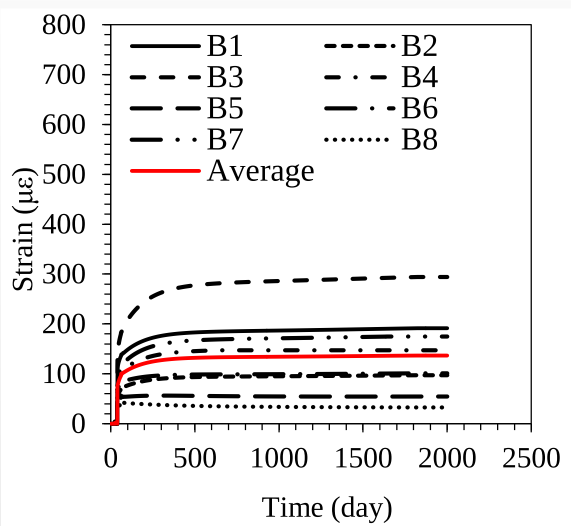
Shortening Strain Rate of the Superstructure Due to Different Components



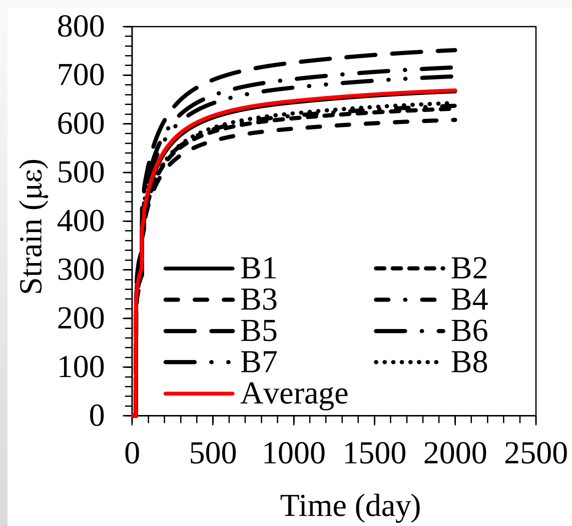
Dead load



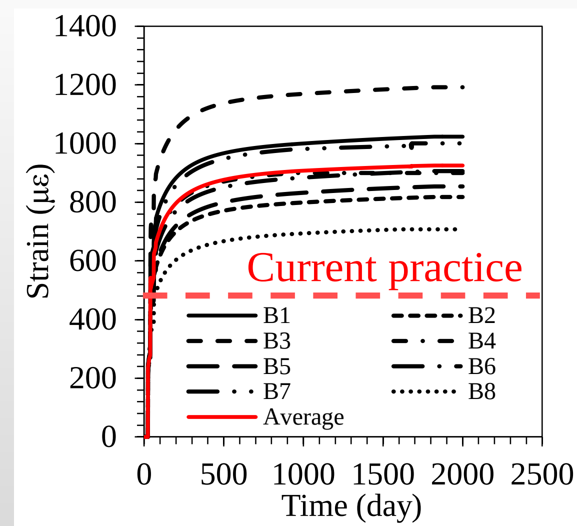
Prestress



Creep



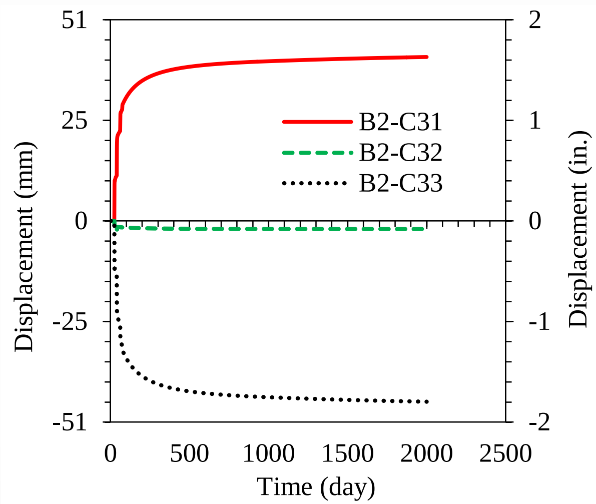
Shrinkage

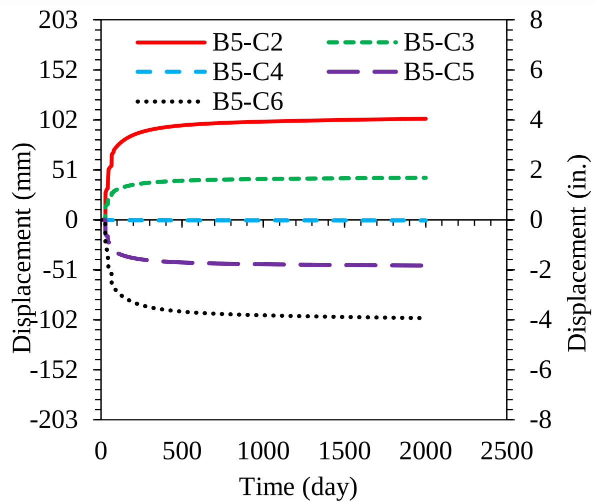


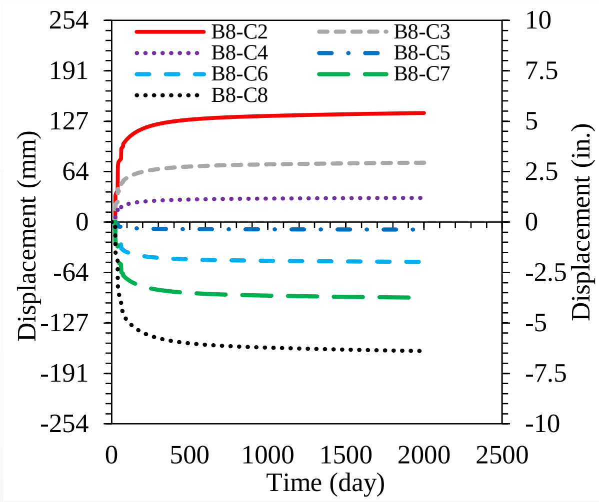
Total

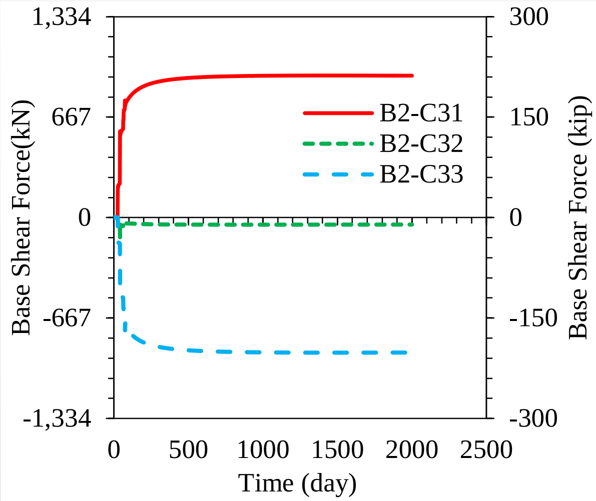
Time-Dependent Effects on PCBB

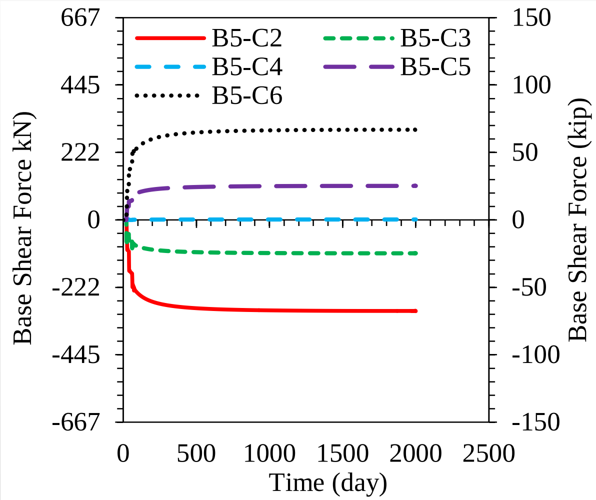
Column Displacements and Shear Forces

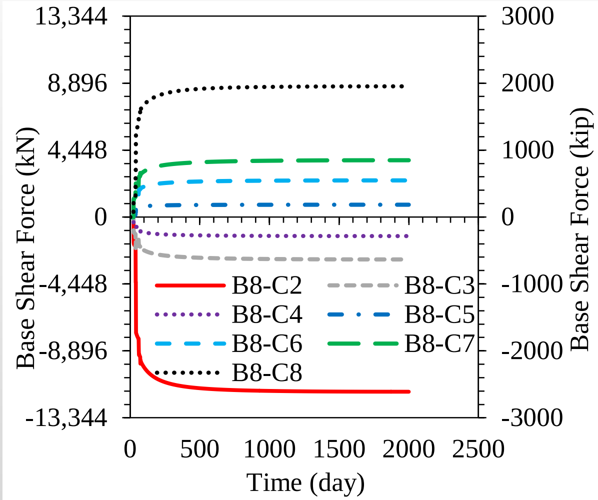












Time-Dependent Effects on PCBB

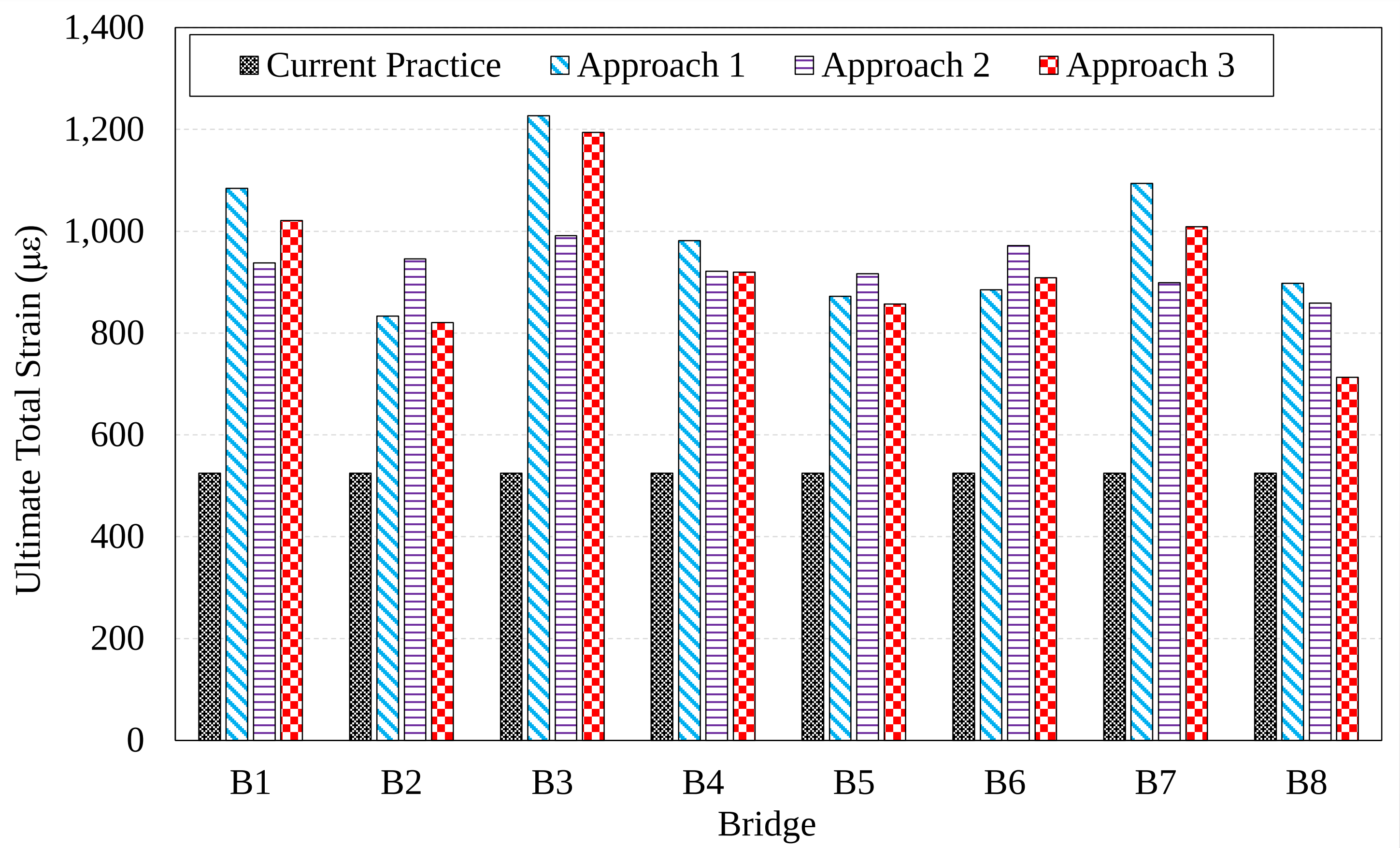
Design Recommendations

- Concrete creep and shrinkage are stabilized after 2000 days
- The ultimate condition for the deformations and forces were defined after 2000 days
- In addition to the current practice, three different simplified approaches were developed

Approach	$\varepsilon_T = \varepsilon_{DL} + \varepsilon_{PS} + \varepsilon_{CR} + \varepsilon_{SH}$				Δ_{col}	K_{col}	Relaxation	F_{col}
	ε_{DL}	ε_{PS}	ε_{CR}	ε_{SH}				
Current practice	ε_T =16 mm./30.5 m = 525 με				$\varepsilon_T \times x_{col}$	0.5 K_g	Unconsidered	$\Delta_{col} \times K_{col}$
Recommended Approach 1	Consider	$\frac{P}{E_C A}$	$\Phi_U \times \varepsilon_{PS}$	ε_U	$\varepsilon_T \times x_{col}$	K_{eff}	Considered	$\frac{\Delta_{col} \times k'_{col}}{(1 + \emptyset_C)}$
Recommended Approach 2	Consider	FEM results for each bridge	FEM results for each bridge	FEM results for each bridge	$\varepsilon_T \times x_{col}$	K_{eff}	Considered	$\frac{\Delta_{col} \times k'_{col}}{(1 + \emptyset_C)}$
Recommended Approach 3	Consider	FEM mean values	FEM mean values	FEM average results	$\varepsilon_T \times x_{col}$	K_{eff}	Considered	$\frac{\Delta_{col} \times k'_{col}}{(1 + \emptyset_C)}$

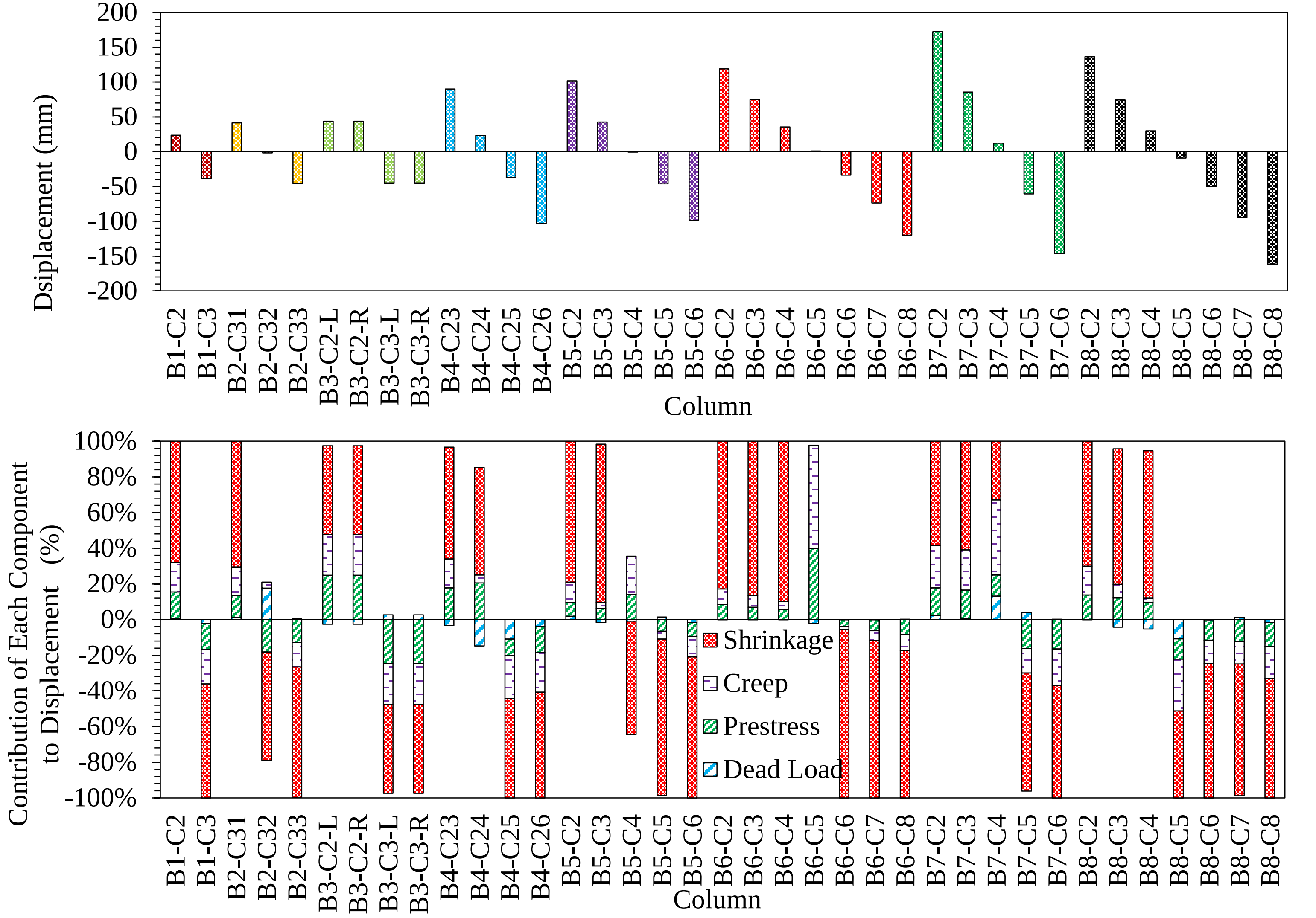
Time-Dependent Effects on PCBB

Ultimate Total Strain for Eight Bridges



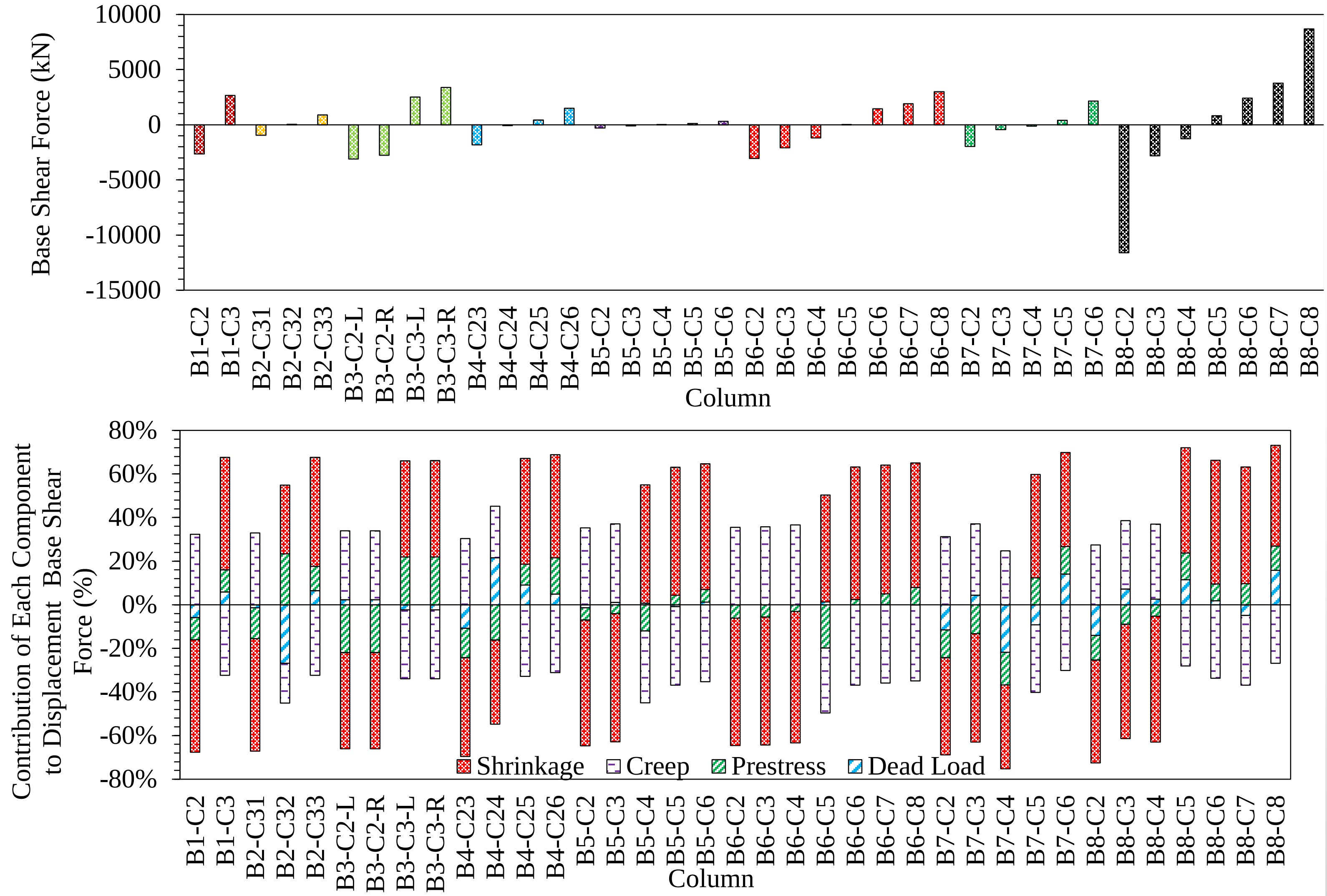
Time-Dependent Effects on PCBB

Ultimate Displacements for 37 Columns



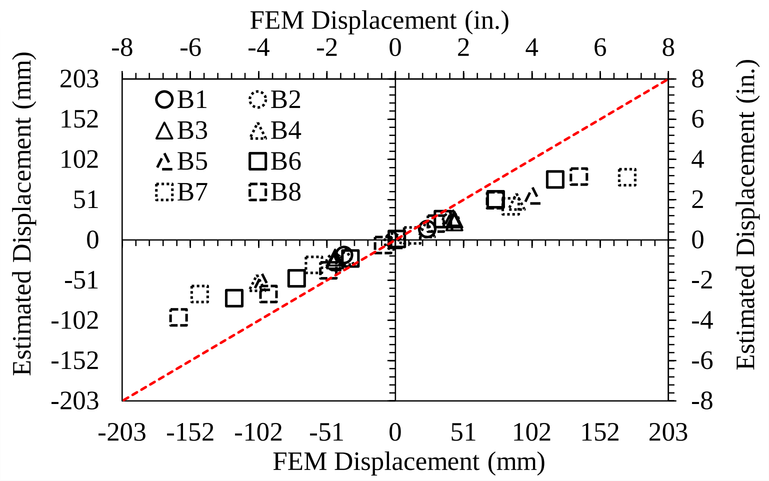
Long-Term Camber of PPCB

Ultimate Base Shear Forces for 37 Columns

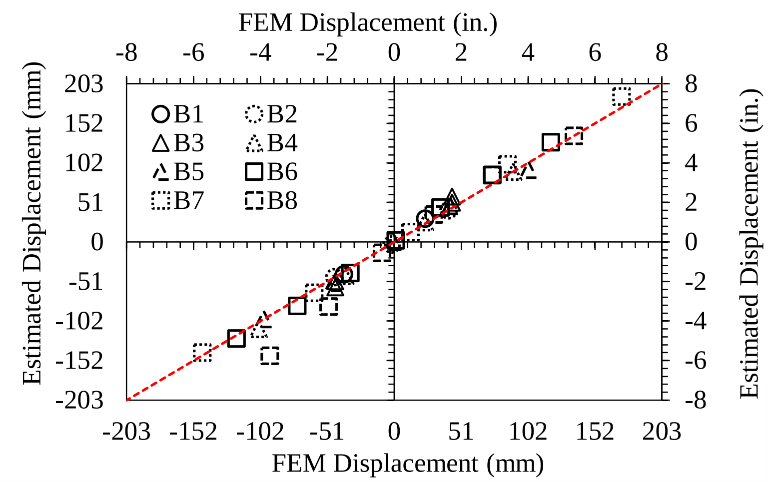


Time-Dependent Effects on PCBB

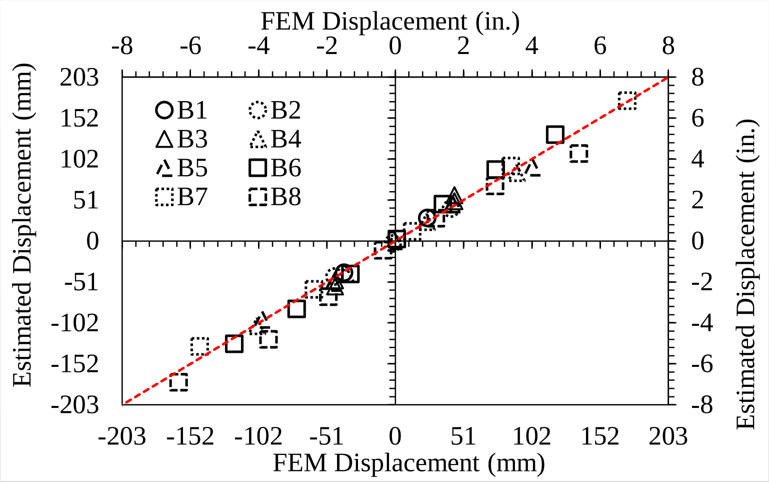
Comparison of the Simplified Methods with the FEA



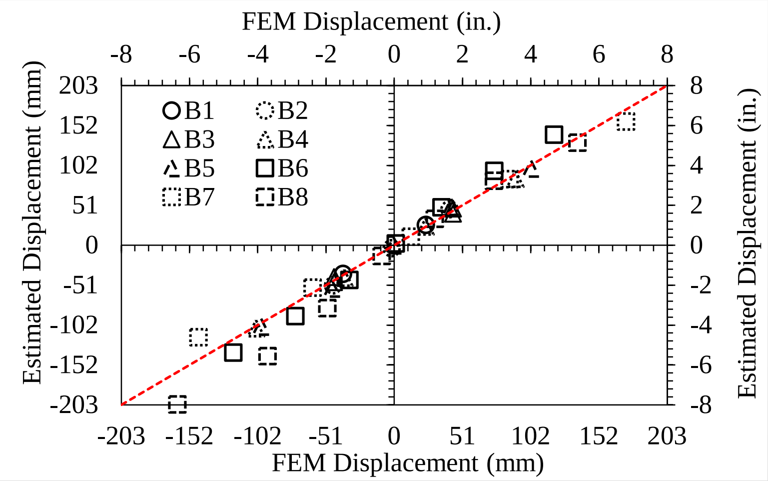
Current practice



Recommended Approach 1



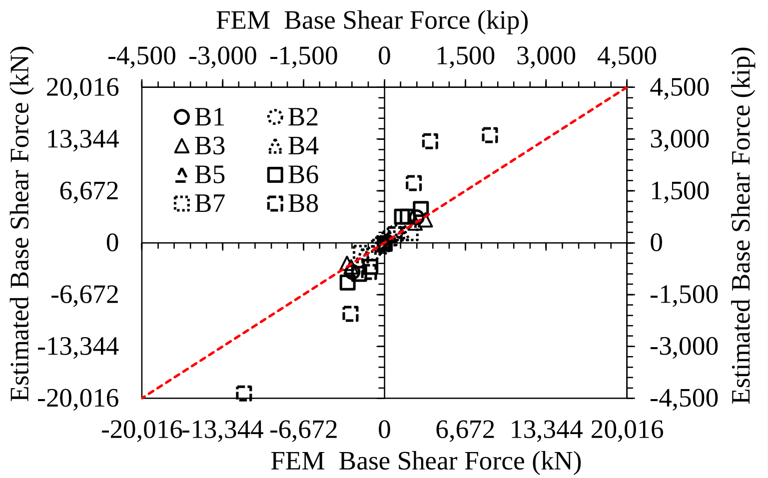
Recommended Approach 2



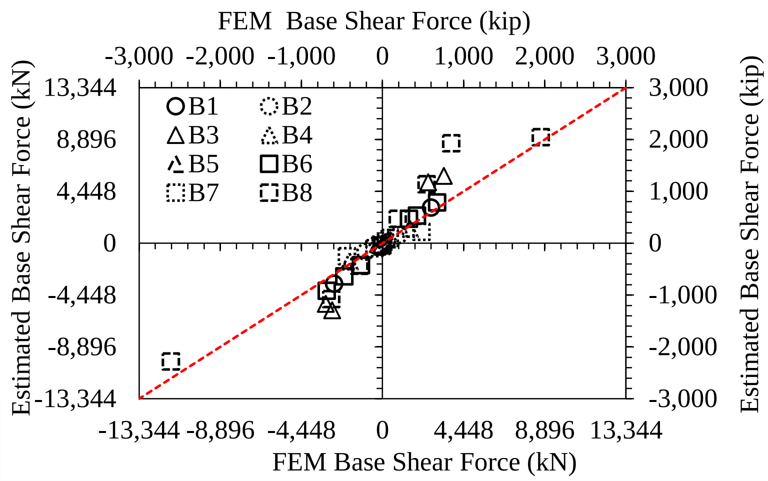
Recommended Approach 3

Time-Dependent Effects on PCBB

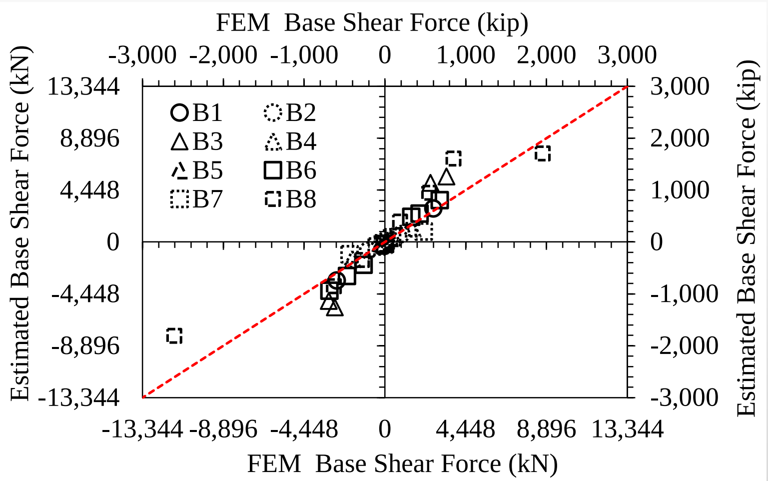
Comparison of the Simplified Methods with the FEA



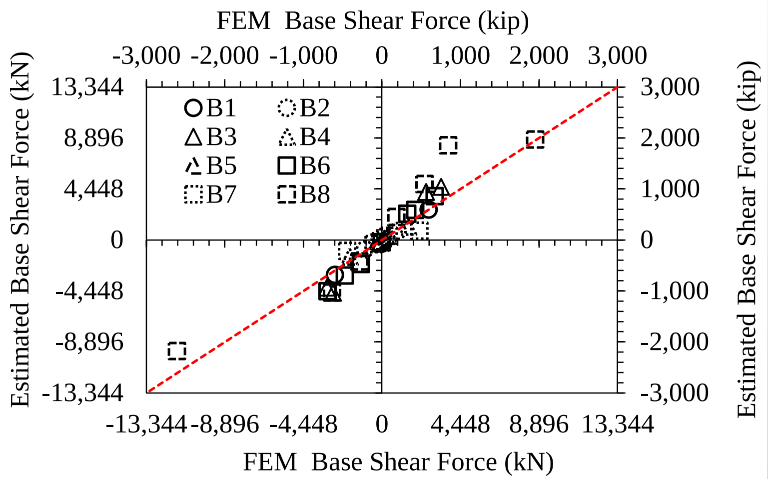
Current practice



Recommended Approach 1



Recommended Approach 2



Recommended Approach 3

Conclusions

- The beneficial effects of concrete relaxation on the displacement-induced columns forces were demonstrated and quantified using an experimental study in conjunction with the FEA of a CIP/PCBB.
- The FEA results from eight different CIP/PCBBs indicated that the shortening strain rate of a superstructure, the column lateral displacement and the corresponding base shear force can be refined to improve the current design practice.
- Using the findings of the FEA, three different simplified approaches were recommended with due consideration to the concrete relaxation to accommodate the time-dependent effects in the design of columns of CIP/PCBB more accurately.