Bridge Assessment as per CS 454

Project Application

Abinash Acharya, Technical Lead – Bridges, WSP

Agenda

Assessment Process, Introduction to CS 454

Post-tensioned Concrete Bridge Assessment

Steel-concrete Composite Bridge Assessment

Abinash Acharya

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Chartered Civil Engineer (CEng MICE, UK)
Professional Engineer (PE, USA)

- 12+ years of experience in Bridge Structural Engineering across the USA & UK
- MSCE (Structural), Lawrence Technological University, Michigan, USA
- Worked on structural assessment of 30+ bridge structures throughout the UK

Wellness Minute

Workplace Hydration

Importance of Hydration:
- Mental & physical wellbeing
- Maintains energy levels
- Improves mood and reduces stress

Recommended Minimum Intake:
Indoor:
Follow the "8x8" rule: eight x 8-ounce (~250ml) glasses daily.

Tips for Staying Hydrated:

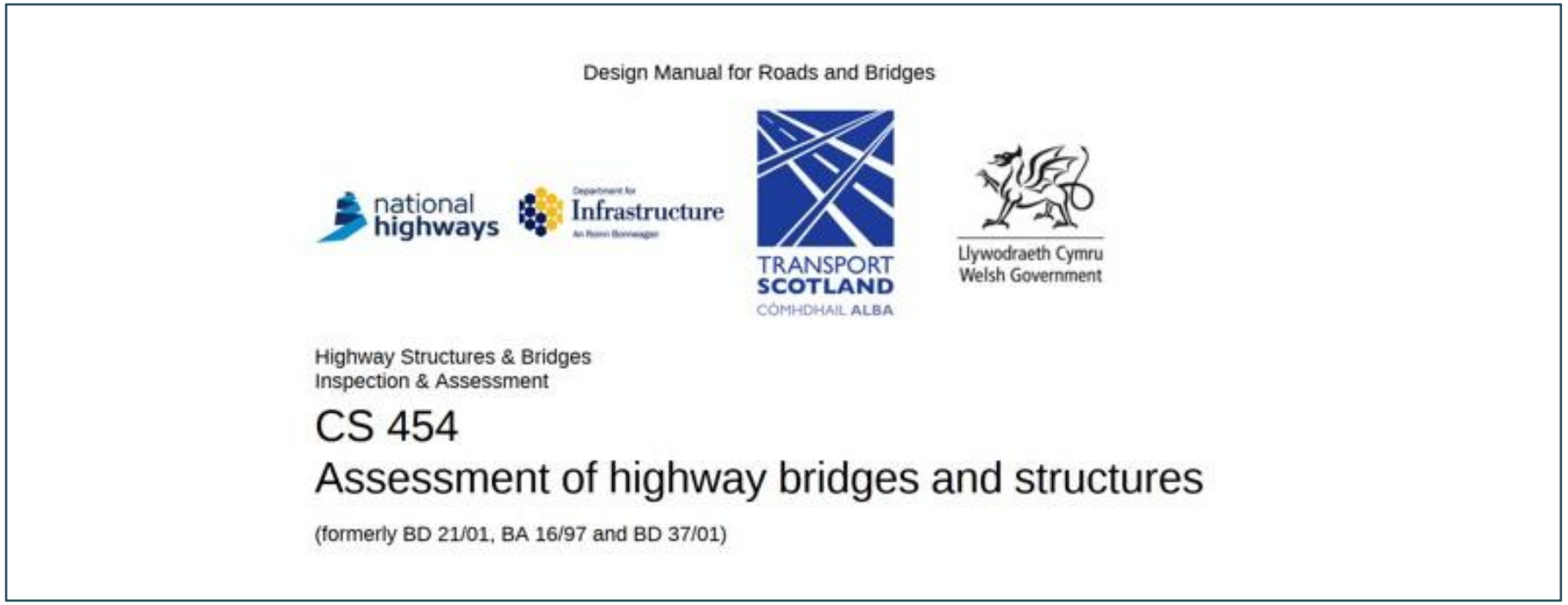
Keep a Water Bottle, Set Reminders, Eat Hydrating Foods

Ref: https://www.osha.gov/sites/default/files/publications/OSHA4372.pdf

How Different Products Play into Hydration

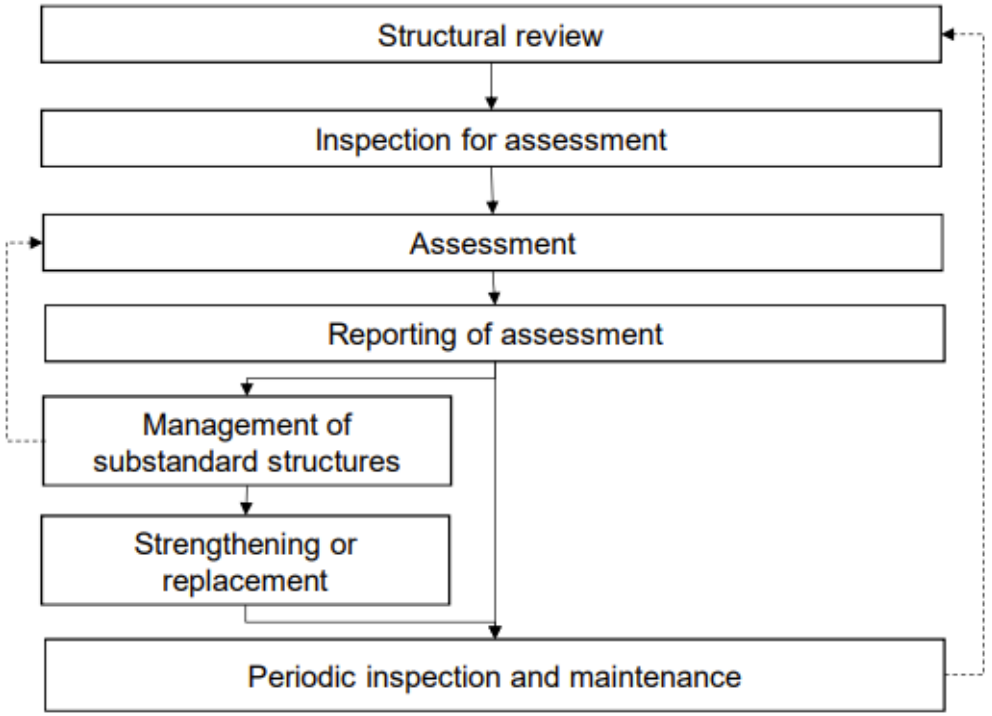
- Alcohol
- Medication
- Caffeine, Energy drinks

Introduction to CS 454 & Assessment Process



Assessment Process

Flow Chart from CS 454



Corresponding DMRB Standards

- CS 451
- CS 450, CS 454, CS 459 & relevant CS documents
- CS 454 & relevant CS documents
- CS 454 & CS 451
- CS 470
- CD 350 & relevant CD documents
- CS 450, relevant CM & CD documents

Assessment Standards - DMRB

CS - Inspection & Assessment

Document Reference	Version	Title	Date of Issue
CS 432	Revision 1	Inspection of buried concrete box structures	Mar-20
CS 450	Version 0.1.0	Inspection of highway structures	29-Apr-2021
CS 451	Revision 0	Structural review and assessment of highway structures	Mar-20
CS 452	Revision 0	Inspection and records for road tunnel systems	Mar-20
CS 453	Revision 0	The assessment of highway bridge supports	Mar-20
CS 454	Version 1.1.0	Assessment of highway bridges and structures	31-Oct-2022
CS 455	Version 1.1.1	The assessment of concrete highway bridges and structures	31-Oct-2022
CS 456	Revision 0	The assessment of steel highway bridges and structures	Mar-20
CS 457	Revision 1	The assessment of composite highway bridges and structures	Mar-20
CS 458	Revision 0	The assessment of highway bridges and structures for the effects of special type general order (STGO) and special order (SO) vehicles	Mar-20
CS 459	Revision 1	The assessment of bridge substructures, retaining structures and buried structures	Mar-20
CS 460	Version 1.0.1	Management of corrugated steel buried structures	30-Apr-2023
CS 461	Version 0.1.0	Assessment and upgrading of in-service parapets	31-Jan-2023
CS 462	Revision 0	Repair and management of deteriorated concrete highway structures	Mar-20
CS 463	Revision 0	Load testing for bridge assessment	Jun-19
CS 464	Revision 1	Non-destructive testing of highways structures	Mar-20
CS 465	Revision 0	Management of post-tensioned concrete bridges	Mar-20
CS 466	Revision 0	Risk management and structural assessment of concrete half-joint deck structures	Mar-20
CS 467	Revision 1	Risk management and structural assessment of concrete deck hinge structures	Apr-20
CS 468	Revision 1	Assessment of Freyssinet concrete hinges in highway structures	Mar-20
CS 469	Version 1.0.0	Management of scour and other hydraulic actions at highway structures.	30-Apr-2024
CS 470	Revision 0	Management of sub-standard highway structures	Mar-20

⇐ **Basis, actions, materials, analysis methods, load comb. etc.**

⇐ Concrete Structures

⇐ Steel Structures

⇐ Composite Structures

⇐ Abnormal traffic actions

⇐ Substructures

⇐ Concrete Half Joint

⇐ Concrete Hinges

⇐ Concrete Hinges

Ref: GG 000, Version 29-Nov-2024

Basis of assessment – CS 454

Method of assessment : Partial factor method (few exceptions, e.g. cast iron, masonry arches)

Limit States: ULS & SLS Limit state,

γ_m - partial factor for material strength
f_k - characteristic, nominal or WC strength of the material
γ_{fL} - Partial factors for actions

γ_{f3} - factor that takes account of inaccurate assessment
F_c - condition factor, only used for Masonry arches, Cast iron

Verification

The structure shall be deemed to be capable of resisting the assessment actions when Equation 3.12 is satisfied.

Equation 3.12 Verification

$$R_a^* \geq S_a^*$$

For structures assessed to CS 456 [Ref 9.N], the verification of Equation 3.12 may alternatively be satisfied using the format in Equation 3.12.1.

Assessment action effects

The assessment action effects, S_a^* , shall be obtained from Equation 3.7.

Equation 3.7 Assessment action effects

$$S_a^* = \gamma_{f3}(\text{effects of}(Q_a^*))$$

γ_{f3} is a factor that takes account of inaccurate assessment of the effects of actions such as unforeseen stress distribution in the structure, inherent inaccuracies in the calculation model, and variations in the dimensional accuracy from measured values.

Assessment resistance

The assessment resistance, R_a^* , shall be determined from the material strengths and section properties using Equation 3.10a or, for cast iron, Equation 3.10b.

Equation 3.10a Assessment resistance

$$R_a^* = F_C(\text{function of}(f_k, \gamma_m))$$

Equation 3.12.1 Alternative verification format for steel structures

$$F_C(\text{function of}(f_k, \gamma_m, \gamma_{f3})) \geq \text{effects of}(Q_a^*)$$

The position of γ_{f3} is different in Equation 3.12 and Equation 3.12.1.

Assessment Results

How to Report Assessment Result ? (Appendix C, CS 451)

- Critical element identity
- Value of appropriate assessment load effects; S* (break up effects due to DL, SIDL, LL)
- Value of assessment resistance; R^*_A
- Mode of failure
- Structural adequacy factor; R^*_A / S^*_A , or reserve factors Ψ^*_{SV} and Ψ_{SV}
- Vehicle rating

$$\Psi_S^* = \frac{R_A^* - S_G^* - S_{ALL}^*}{S^*}$$

where:

Ψ_S^*	is the reserve factor (for SV, SOV, STGO and SOV load models)
R_A^*	= assessment resistance
S_G^*	= assessment load effect due to combined dead and superimposed loads
S_{ALL}^*	= assessment load effect due to the effects of ALL
S^*	= assessment load effect due to the special vehicle (SV, SOV, STGO or SO) under consideration

CS 454 – Assessment Actions

5. Assessment actions

General

5.1 The actions to be assessed shall be defined using rep

5.2 The actions to be assessed shall include:

1) dead and superimposed dead load;
2) carriageway traffic loading;
3) accidental vehicle loading;
4) footway loading.

5.2.1 The actions to be assessed may include:

1) wind loading;
2) thermal loading;
3) longitudinal traffic loading.

Ref: CS 454

CS 455 Concrete: Creep & Shrinkage, Prestress
CS 456 & 457 Steel: Fatigue
CS 459: Earth pressure

Some other LL actions not covered above

- Centrifugal effects (CS 454)
- Collision on bridge support (CS 453)
- Traffic surcharge effects (CS 459)

Design Manual for Roads and Bridges

highways england | TRANSPORT SCOTLAND / CÒMHDHAIL ALBA | Llywodraeth Cymru Welsh Government | Department for Infrastructure / An Roinn Bonneagair

Collision on bridge support

Highway Structures & Bridges
Inspection & Assessment
CS 453
The assessment of highway bridge supports
(formerly BD 48/93, BD 60/04 and IAN 91/07)
Revision 0

Normal Traffic, Restricted Traffic

Highway Structures & Bridges
Inspection & Assessment
CS 454
Assessment of highway bridges and structures
(formerly BD 21/01, BA 16/97 and BD 37/01)
Version 1.1.0

Concrete - Creep, Shrinkage, prestress

Highway Structures & Bridges
Inspection & Assessment
CS 455
The assessment of concrete highway bridges and structures
(formerly BD 44/15, BA 38/93, BA 40/93, BA 51/95 and BA 52/94)
Version 1.1.1

Steel- Fatigue, relaxation

Highway Structures & Bridges
Inspection & Assessment
CS 456
The assessment of steel highway bridges and structures
(formerly BD 56/10)
Revision 0

Steel- Fatigue, relaxation

Highway Structures & Bridges
Inspection & Assessment
CS 457
The assessment of composite highway bridges and structures
(formerly BD 61/10)
Revision 1

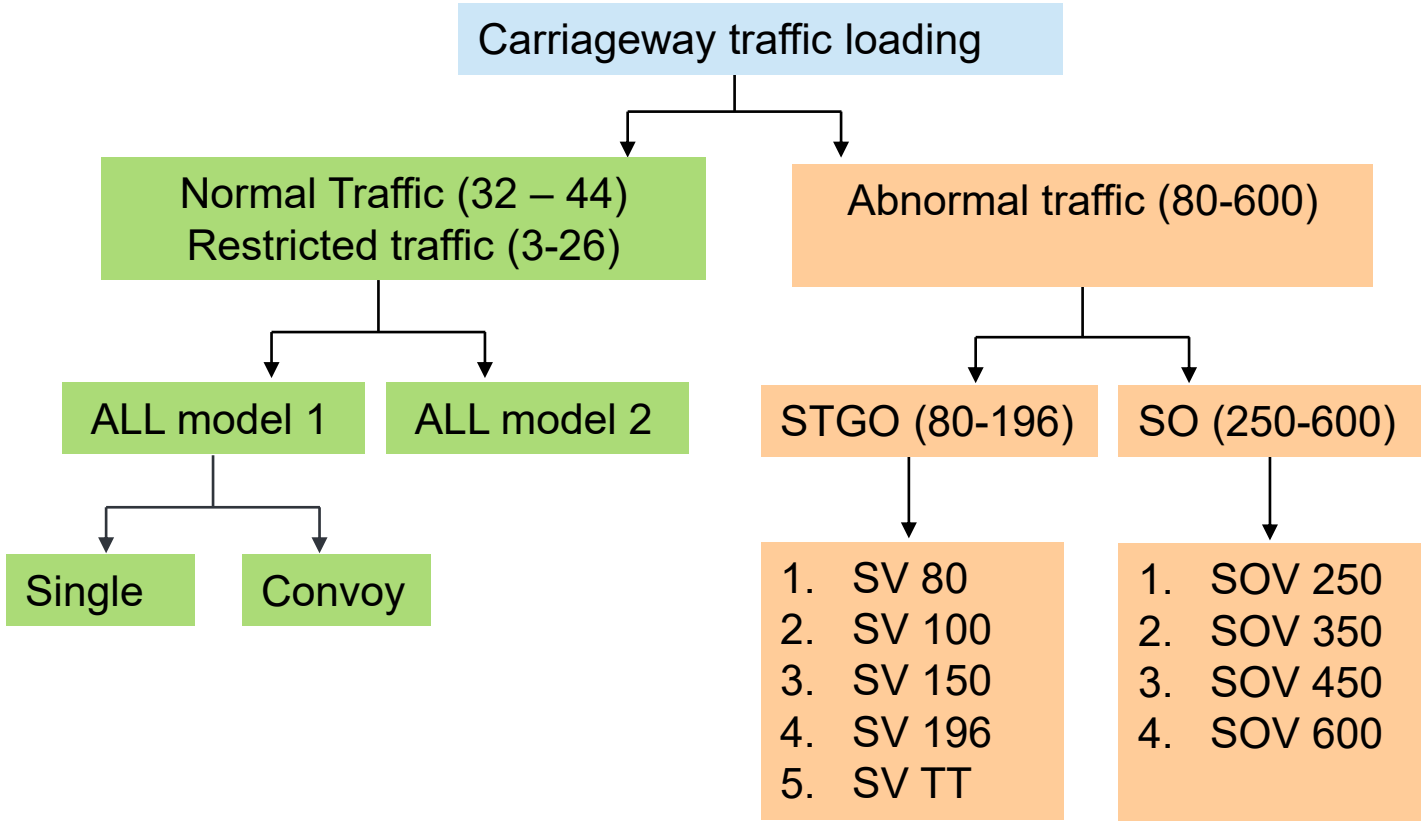
STGO & SO Load

Highway Structures & Bridges
Inspection & Assessment
CS 458
The assessment of highway bridges and structures for the effects of special type general order (STGO) and special order (SO) vehicles
(formerly BD 86/11)
Revision 0

LL Surcharge

Highway Structures & Bridges
Inspection & Assessment
CS 459
The assessment of bridge substructures, retaining structures and buried structures
(formerly BA 55/06)
Revision 1

CS 454 - Carriageway traffic loading



- ALL : Assessment Live Load
- STGO : Standard Types General Order
- SO : Special Order
- Loads shown in bracket () max GVW in metric tonnes
- What traffic loading should be applied for your assessment ? AIP should answer it.
- HB load has been withdrawn from CS454.

Table 7.6.2 SV models to be used in the design

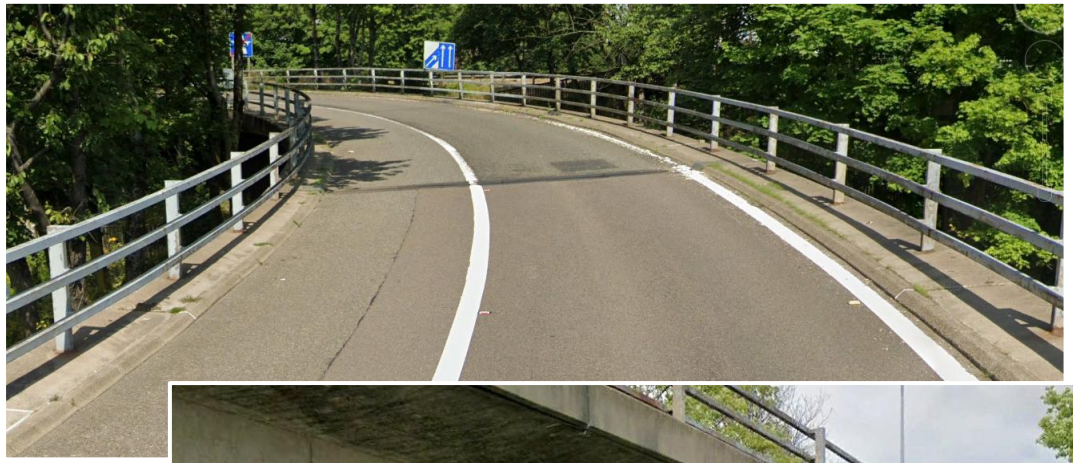
Class or road carried by highway structure	SV models
Motorway and all-purpose trunk roads Principal road extensions of trunk roads	SV80, SV100, SV196
Principal roads as agreed by TAA	SV80, SV100
Other Public roads as agreed by TAA	SV80

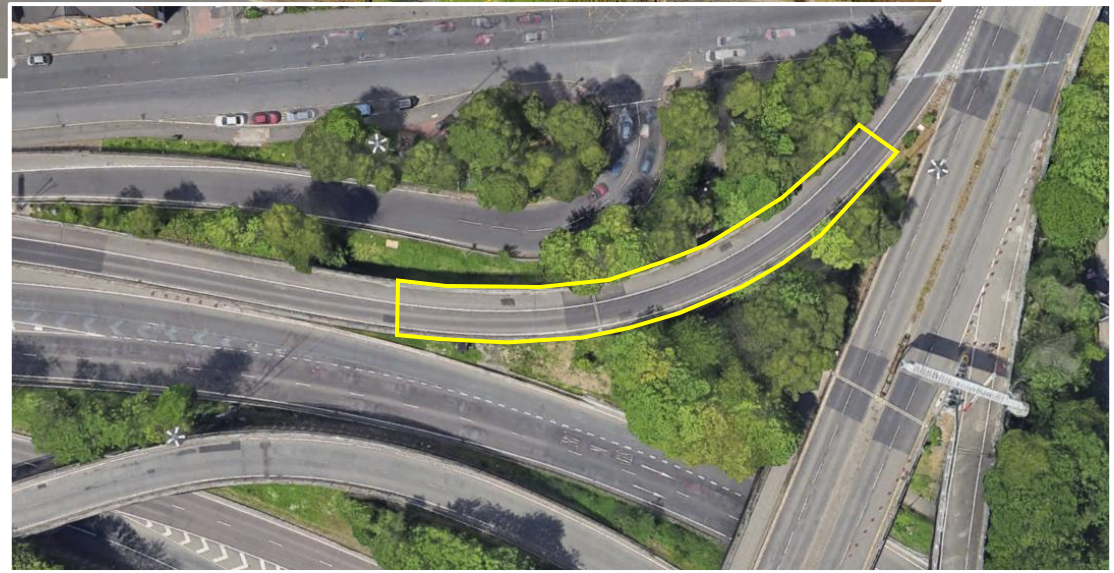
Ref: DMRB CD 350

Post-tensioned Concrete Bridge Assessment

Post-tensioned Concrete Bridge Assessment

- Superstructure: In-situ **post-tensioned RC twin cell box girders**, 5 spans of ~18m each span
- ~10m **central suspended span**, **supported on half joints;** The central suspended span is also a twin cell box but is **not post-tensioned**
- **Transverse diaphragms** are present over intermediate supports; Bridge **carries one traffic lane with a hard shoulder**





Bridge Assessment as per CS 454, Project Application

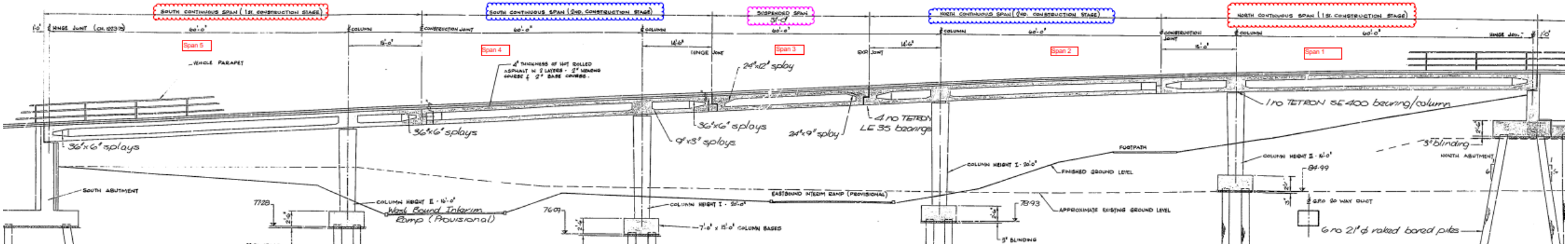
Ref: Google earth imagery

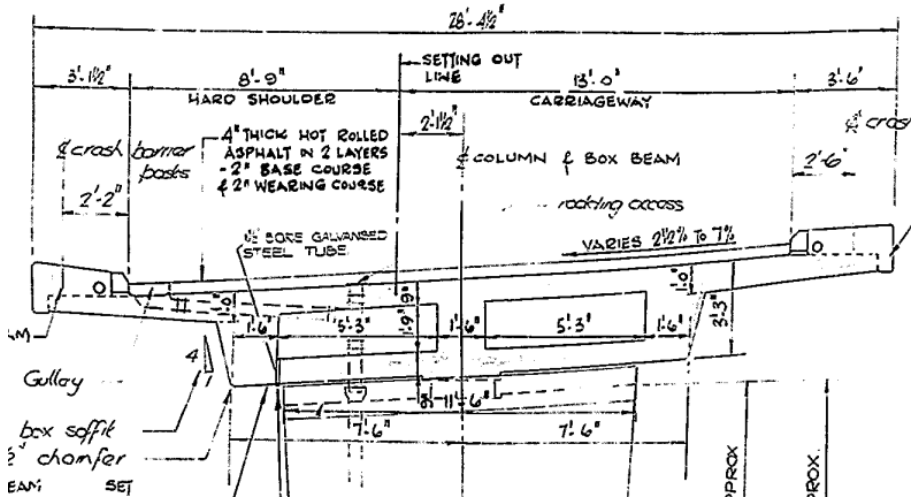
Post-tensioned Concrete Bridge Assessment

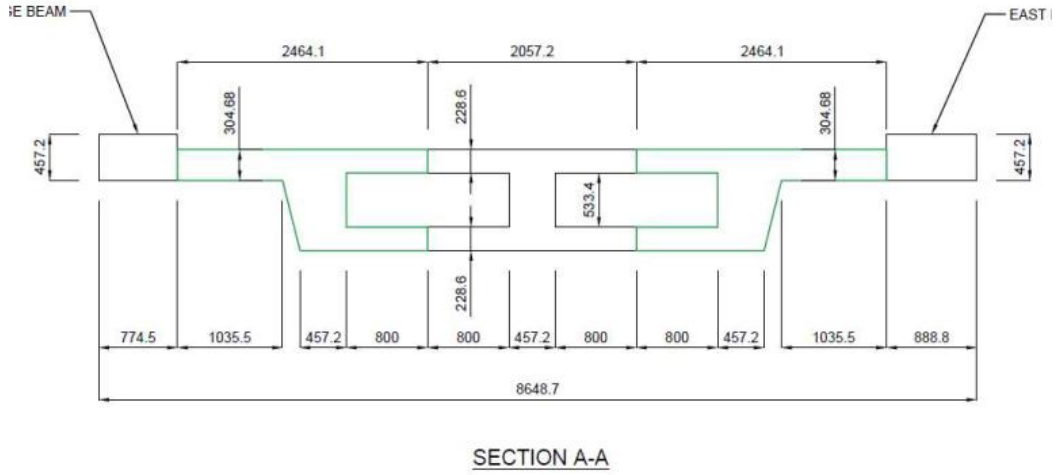
General Arrangement

Articulation :

- Abutments- pinned, concrete hinge; Pier supports – Free sliding bearing
- HJ North- Free sliding bearing; HJ South- pinned, vertical dowels







SECTION A-A

dimensions are in millimetres.

Post-tensioned Concrete Bridge Assessment

Assessment Scope:

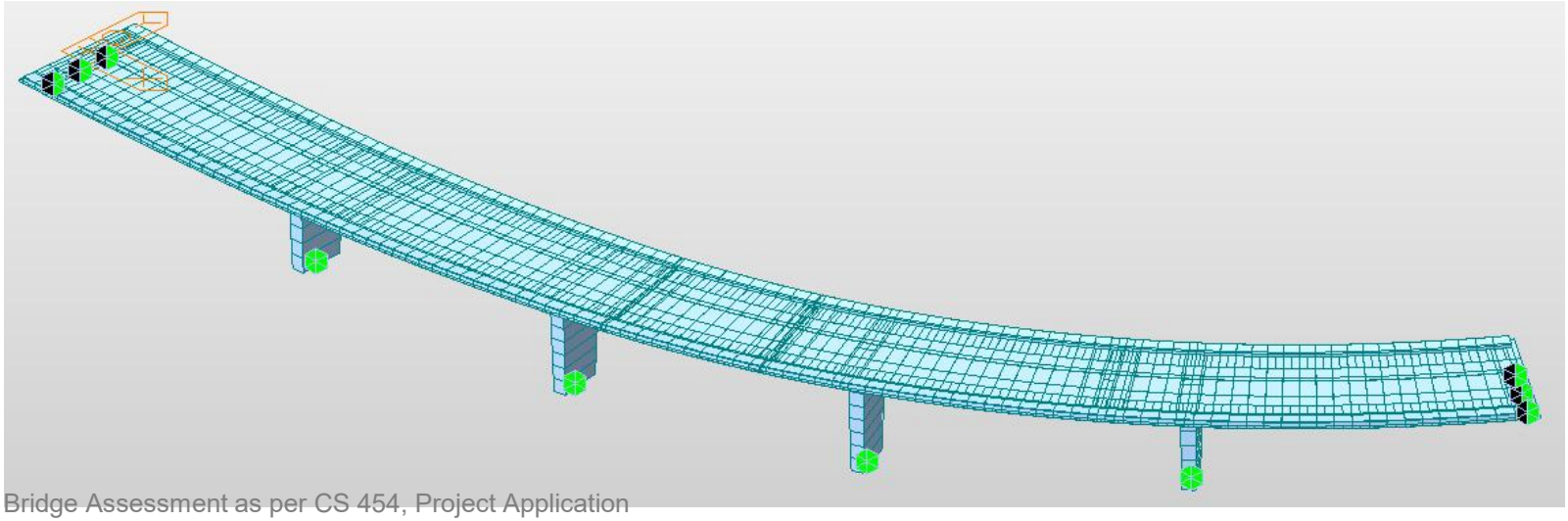
- Superstructure – CS 455
- Concrete Hinge- CS 468
- Half joints – CS 466
- Piers- CS 453

Actions:

- Permanent loads, SIDL, Thermal
- Snow/Wind (ignored)
- Live Load – ALL model 2, 45HB, SV loadings

Structural Analysis:

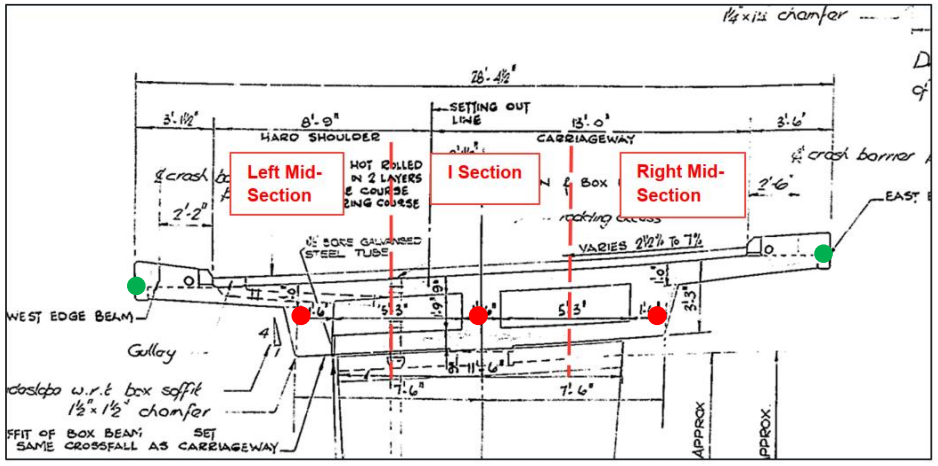
- 2D linear elastic **grillage** global model
- **ULS & SLS** verifications
- Half joints by **STM**
- Include original **construction staging**
- Transverse assessment of deck (**separate plate model** using MIDAS civil)
- Separate **STM** for **diaphragm-** '**deep beam**' due to their span-to-depth ratio



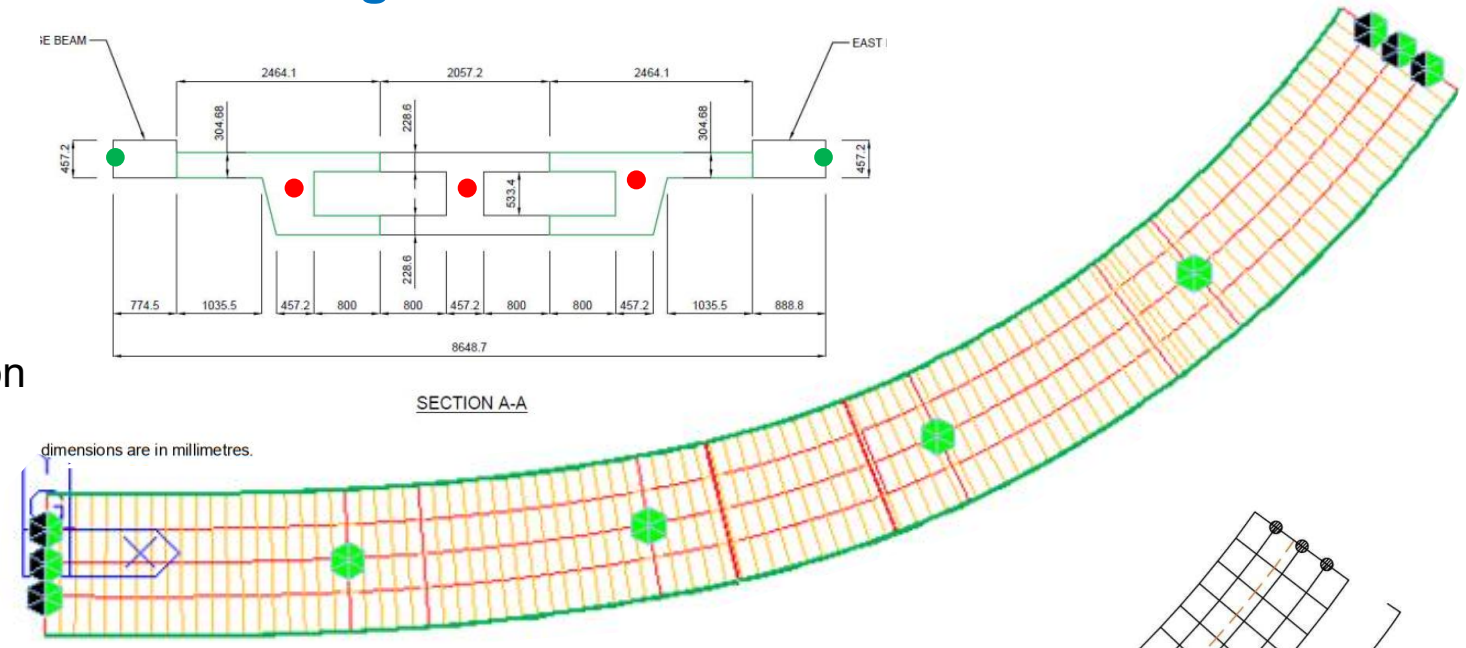
Post-tensioned Concrete Bridge Assessment

Superstructure Grillage Model

- Longitudinal members aligned with webs
- Transverse members orthogonal to deck
- Transverse stiffness per Hambly
- Diaphragms at abutments, piers, half-joints
- Pre-stressing tendons modelled
- Time dependent material prop, Staged construction
- Boundary conditions as per AIP
- Load Application as per AIP

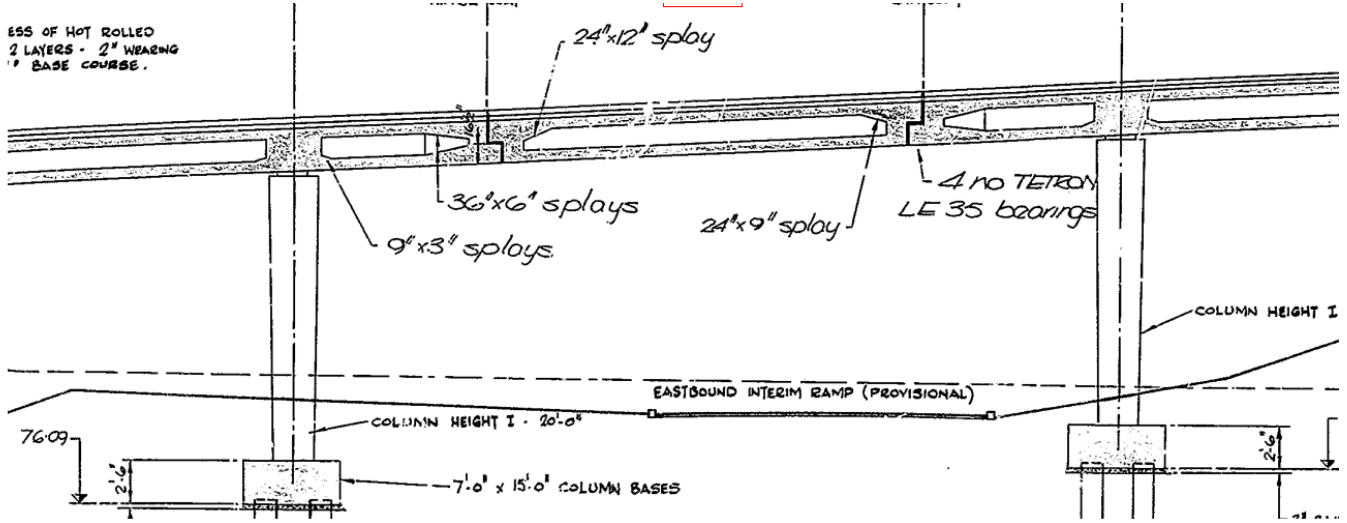


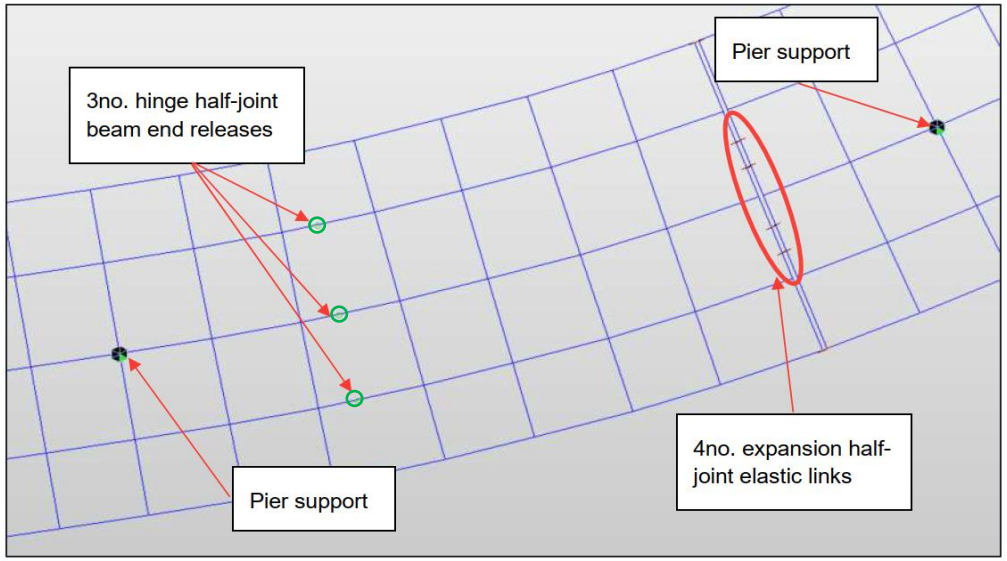
Bridge deck cross-section with longitudinal members labelled



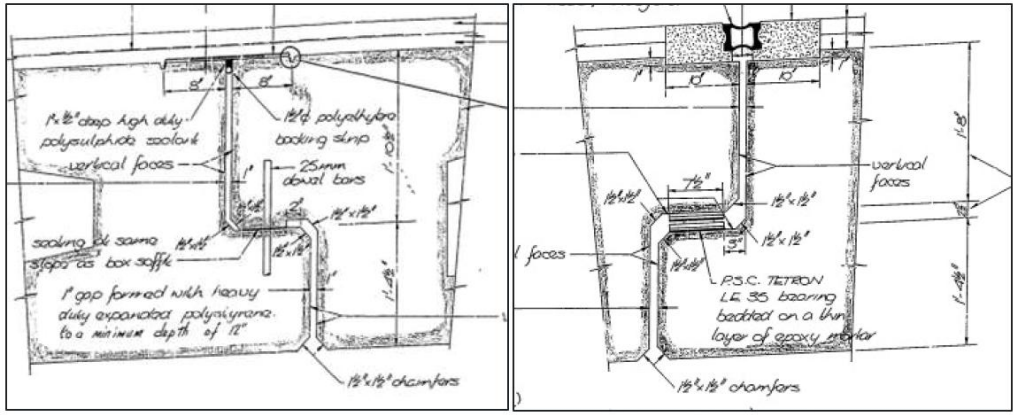
Post-tensioned Concrete Bridge Assessment

Half Joint Details





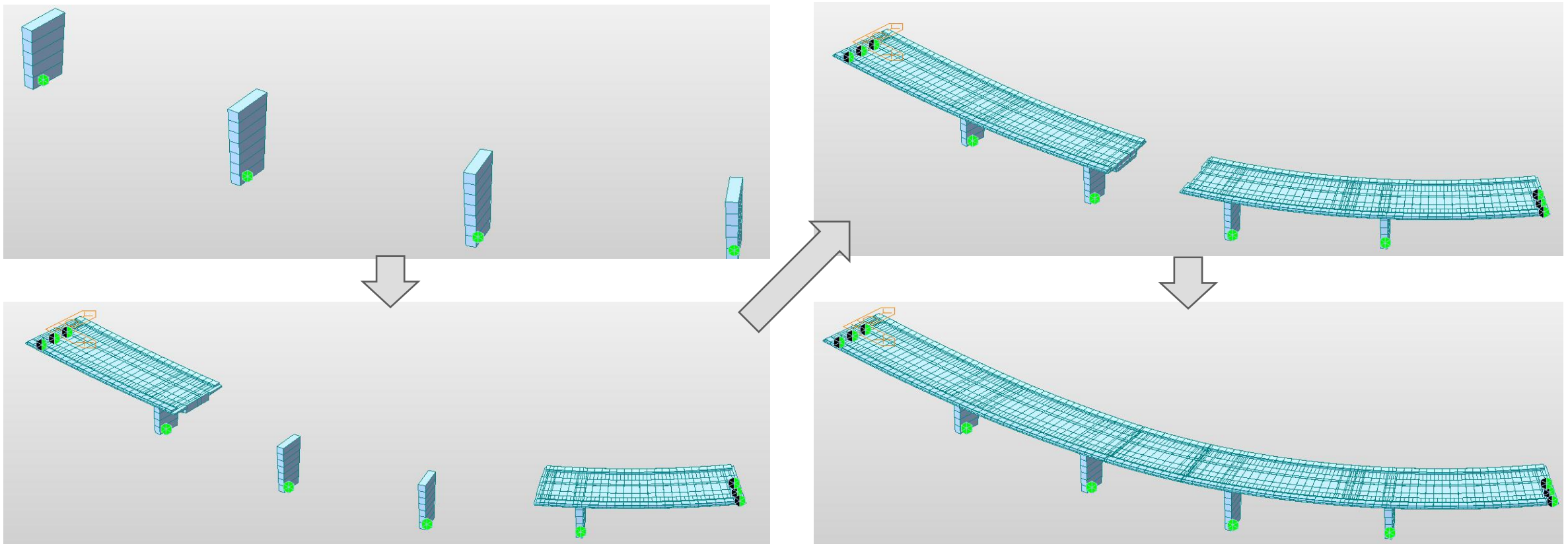
Modelling of half-joints



Half-joints - southern hinge (left) & northern expansion (right)

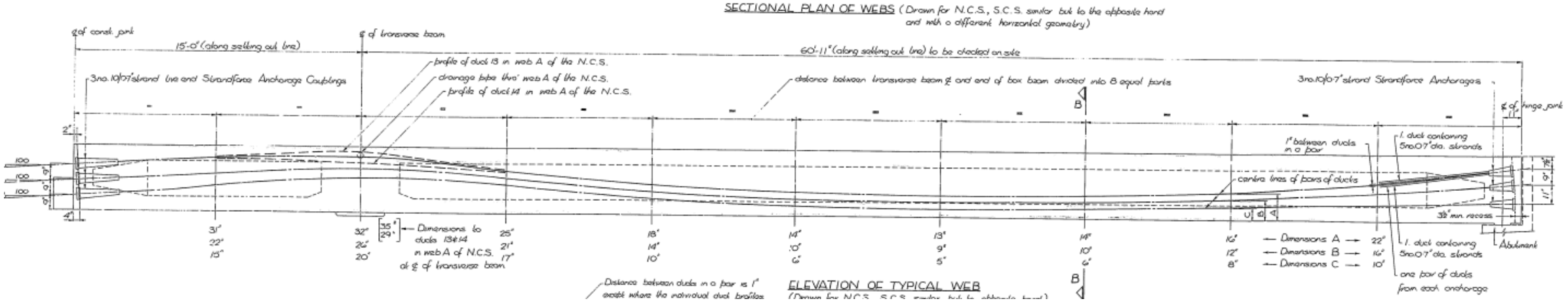
Post-tensioned Concrete Bridge Assessment

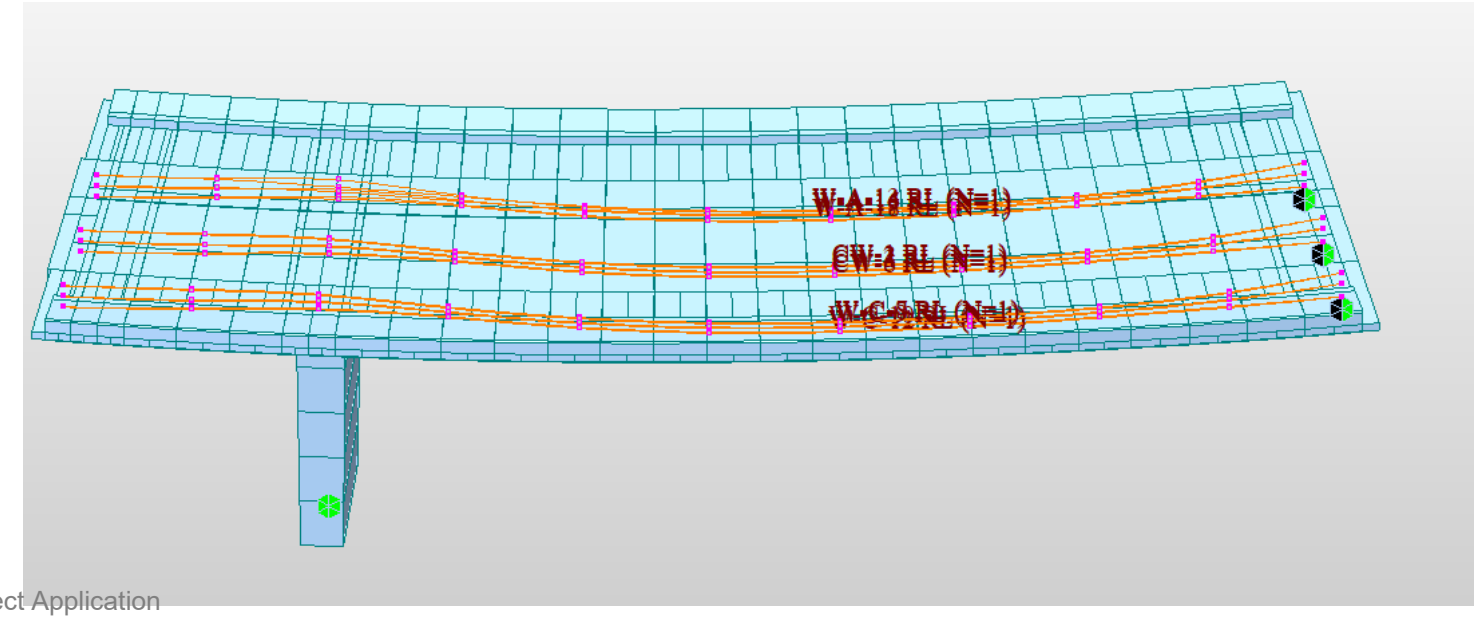
Construction Stages



Post-tensioned Concrete Bridge Assessment

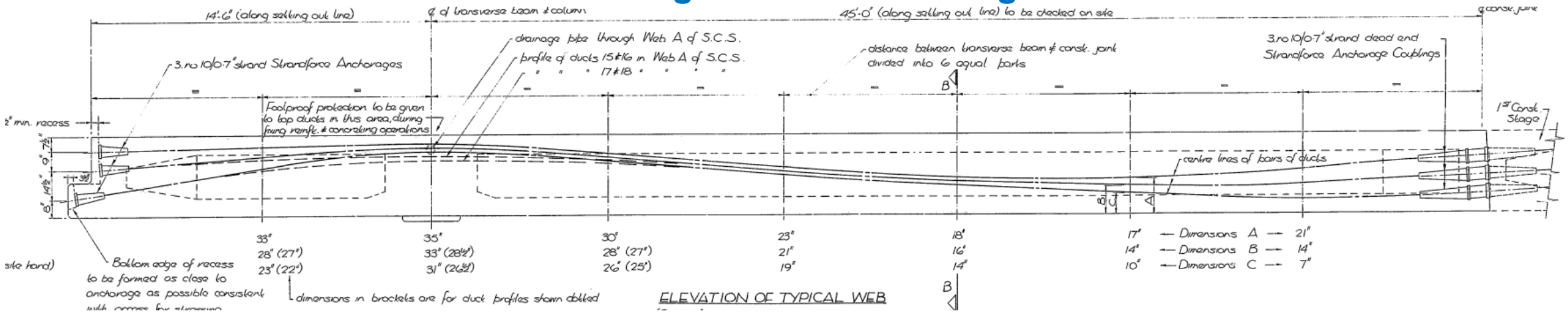
Staged Post Tensioning

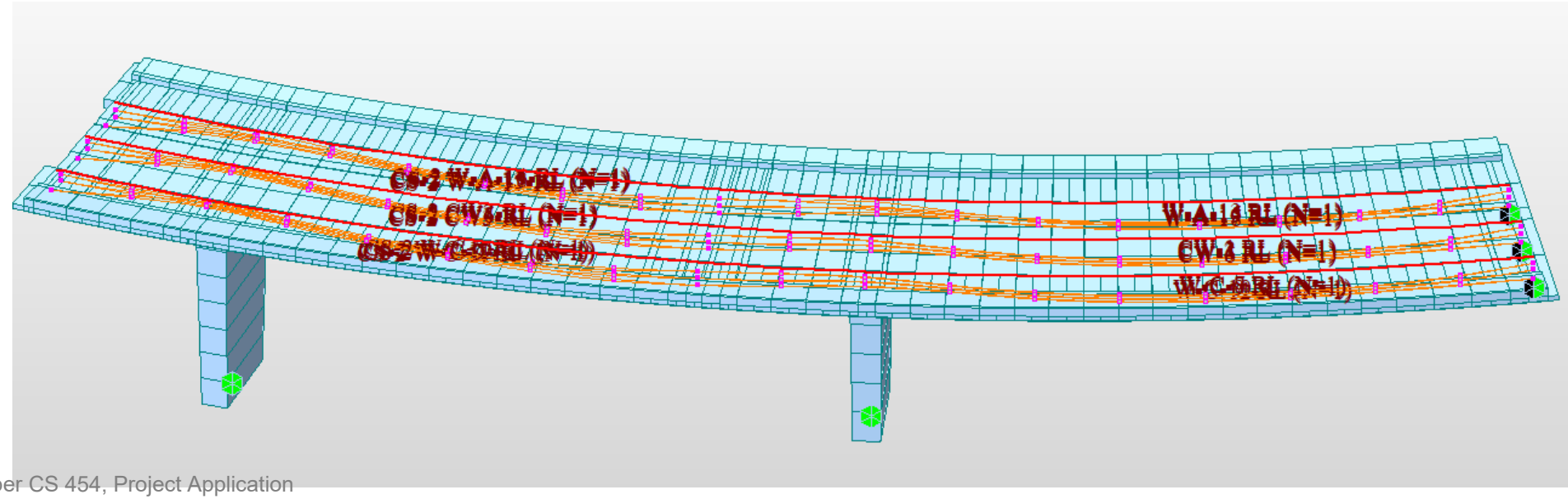




Post-tensioned Concrete Bridge Assessment

Staged Post Tensioning



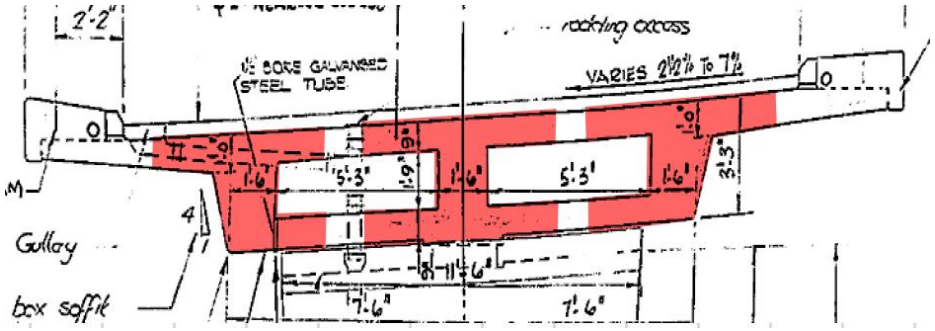


Post-tensioned Concrete Bridge Assessment

SLS Analysis

Shear lag effect as per CS 455 4.16

- **Shear lag effect** applicable in SLS only, not in ULS
- **Effective flange** - web width plus one-tenth of the distance between points of zero moments, on each side
- DMRB code is silent on the distance between zero moments, so can be taken from an analytical model or refer to EC2-1-1- 5.3.2.1



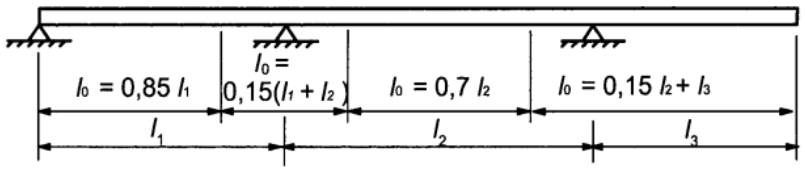
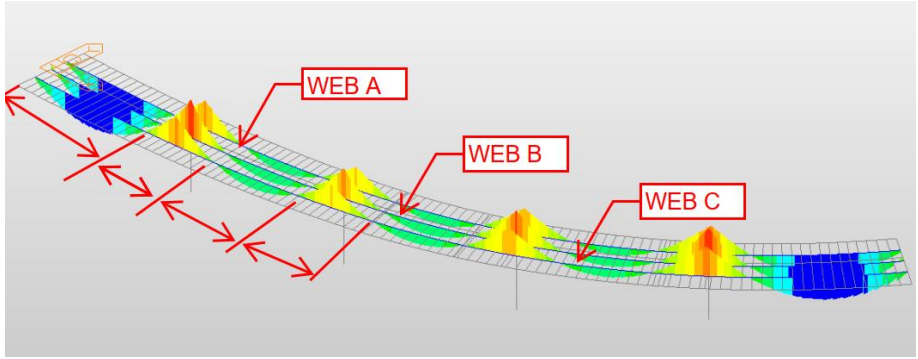
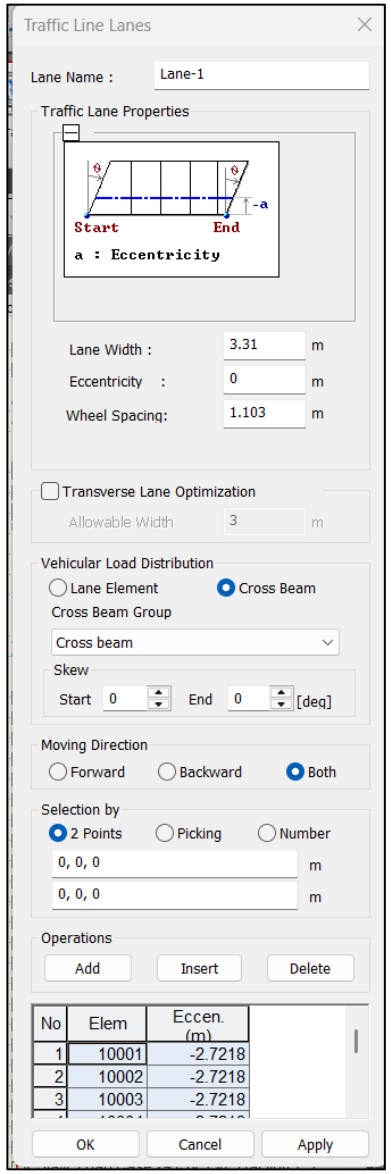
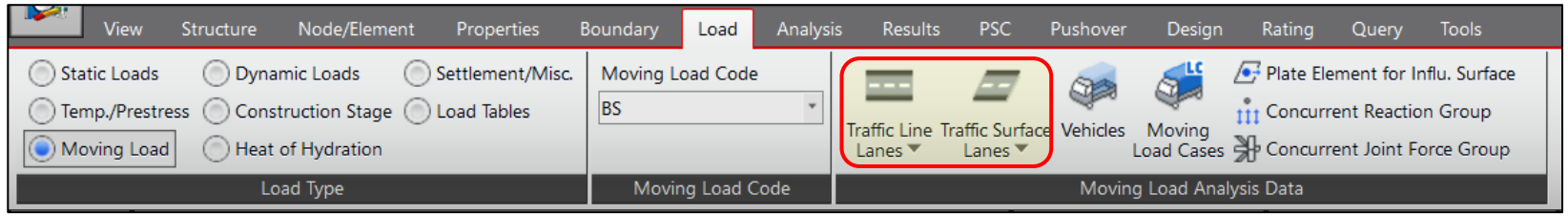


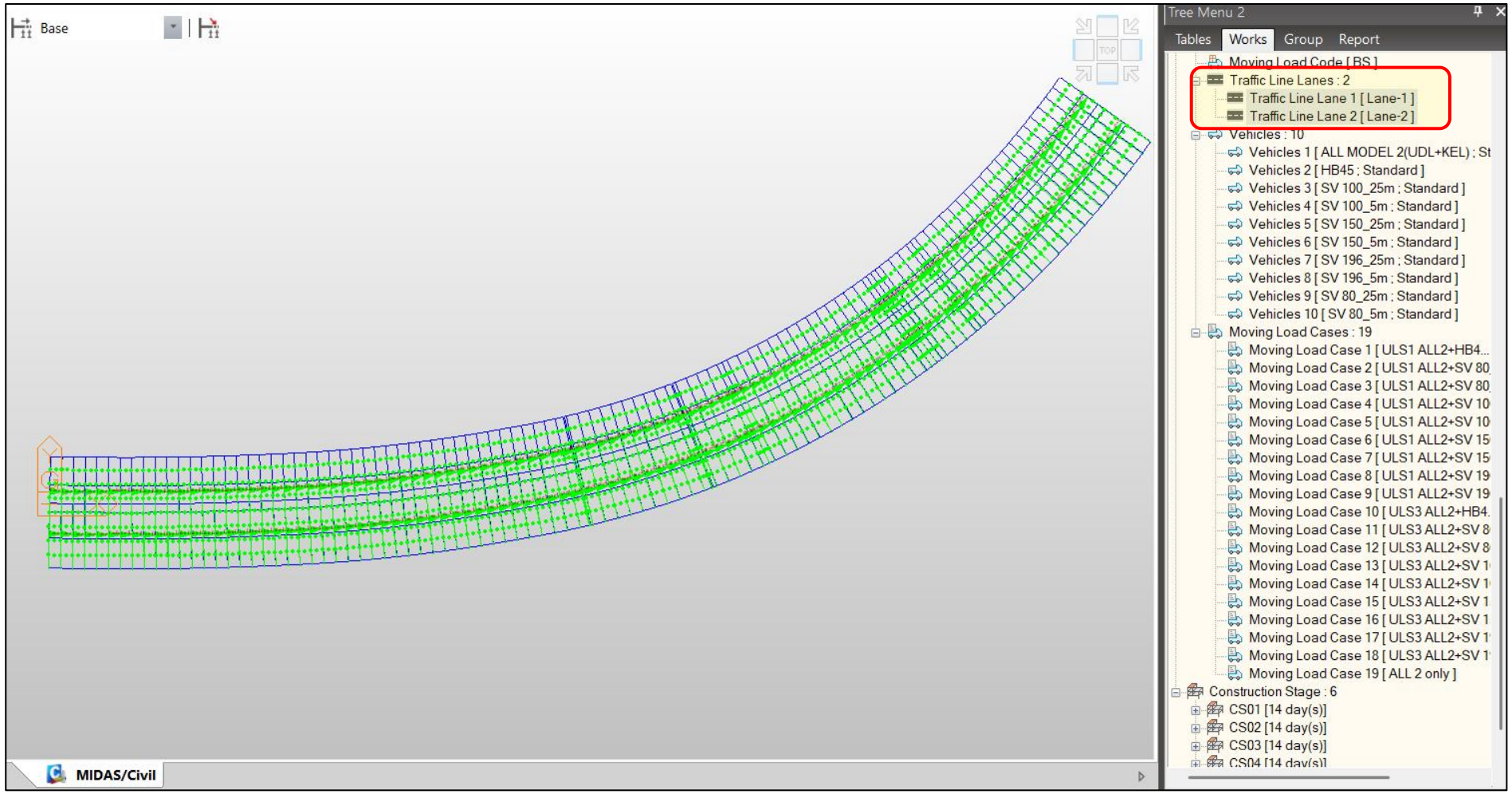
Figure 5.2: Definition of l_0, for calculation of effective flange width



CS 454 Moving Load Application

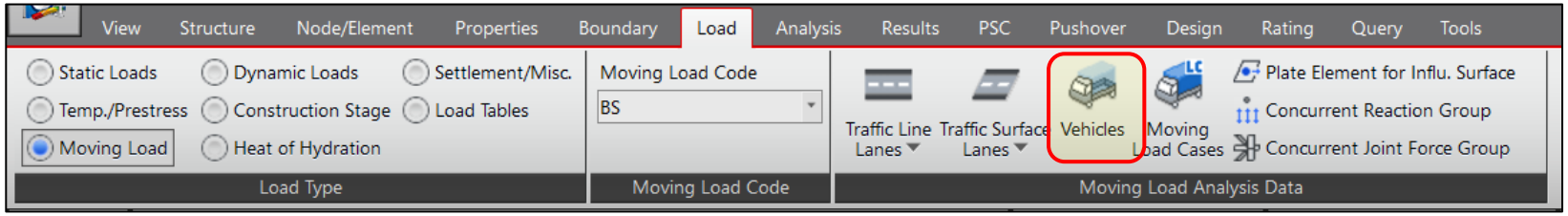




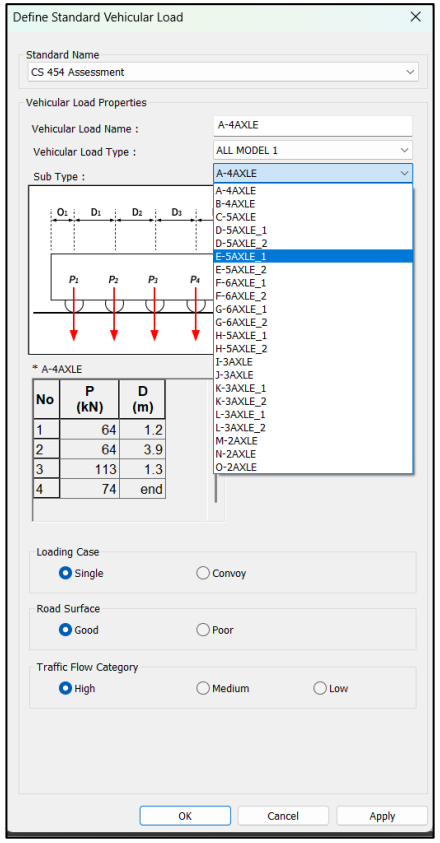


CS 454 Moving Load Application

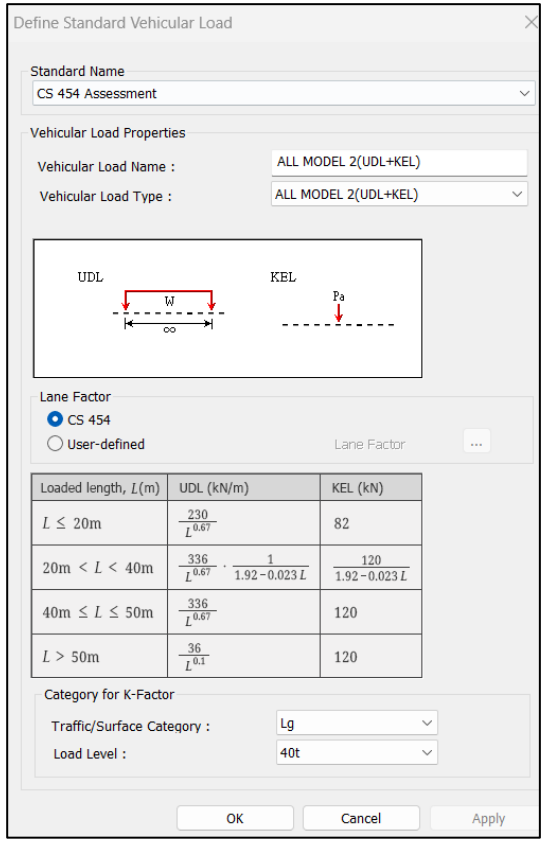
Vehicle library has the predefined vehicles as per CS 454 & CS 458



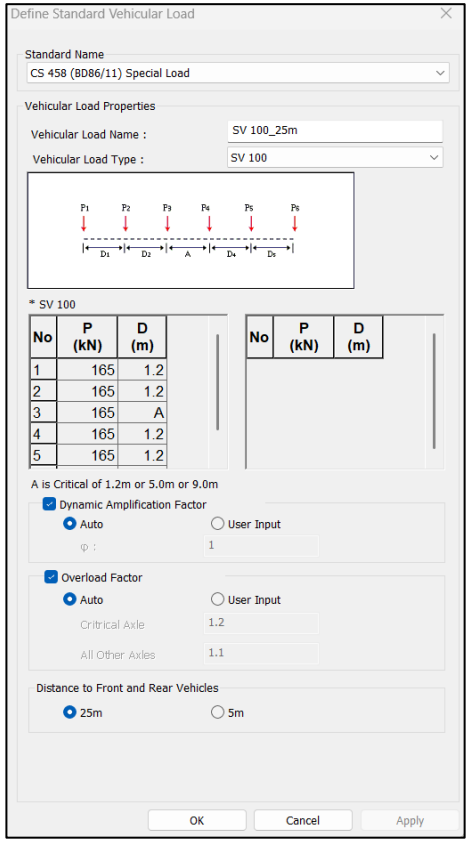
ALL Model 1



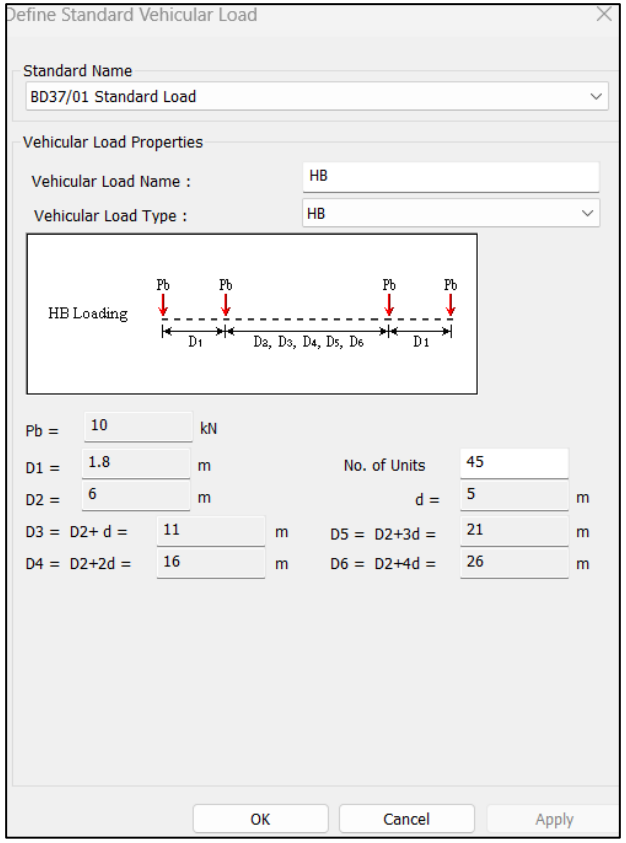
ALL Model 2

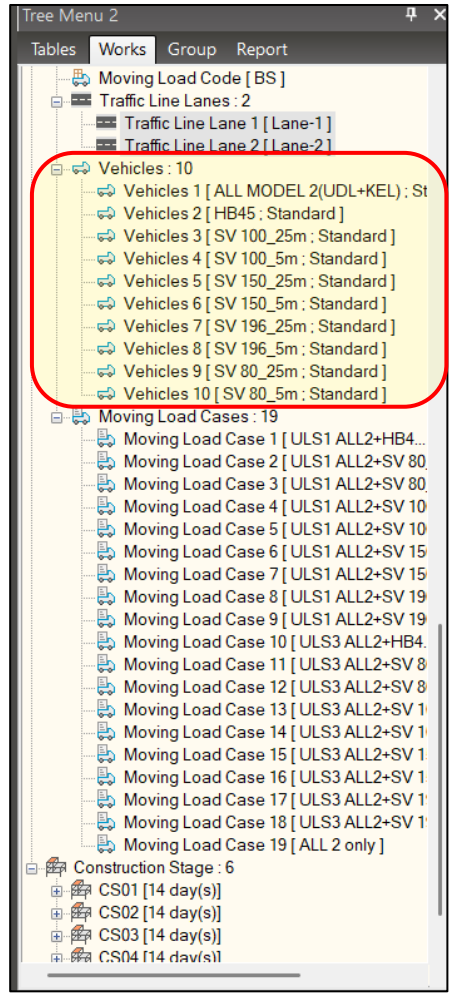


SV



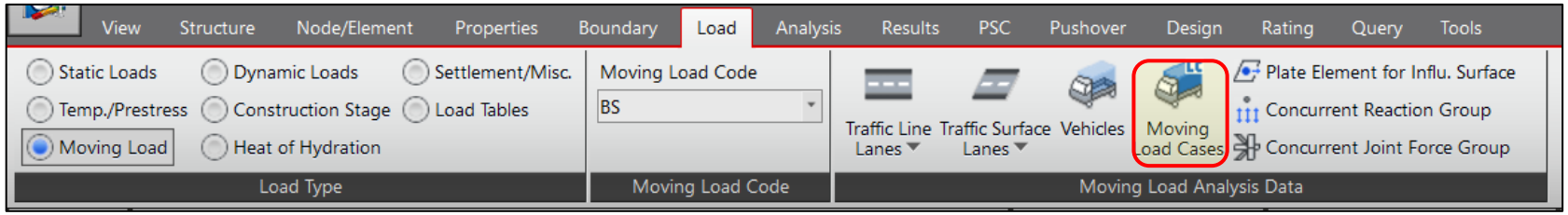
HB

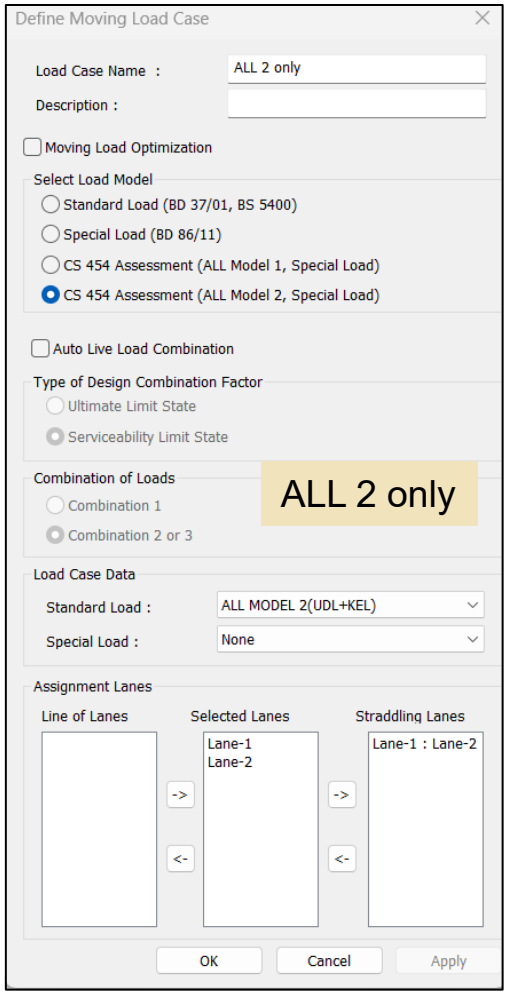


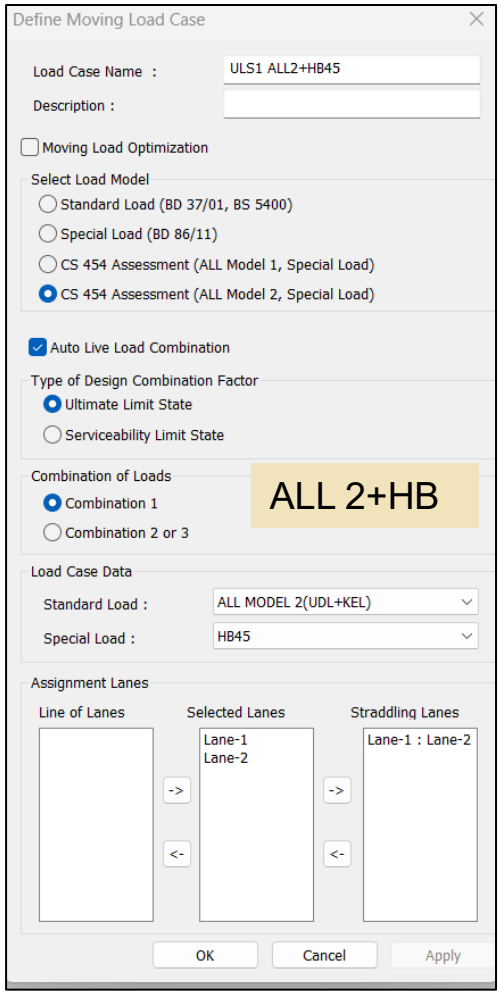


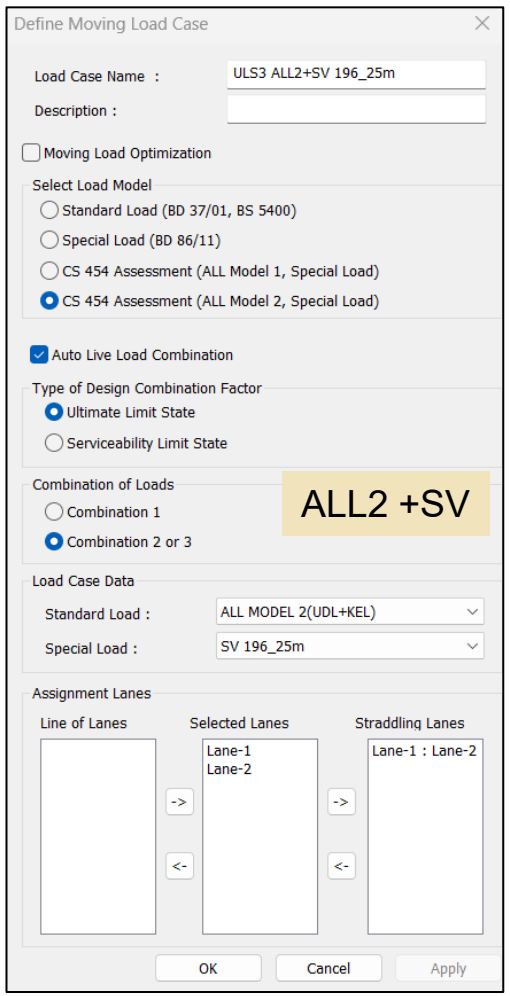
CS 454 Moving Load Application

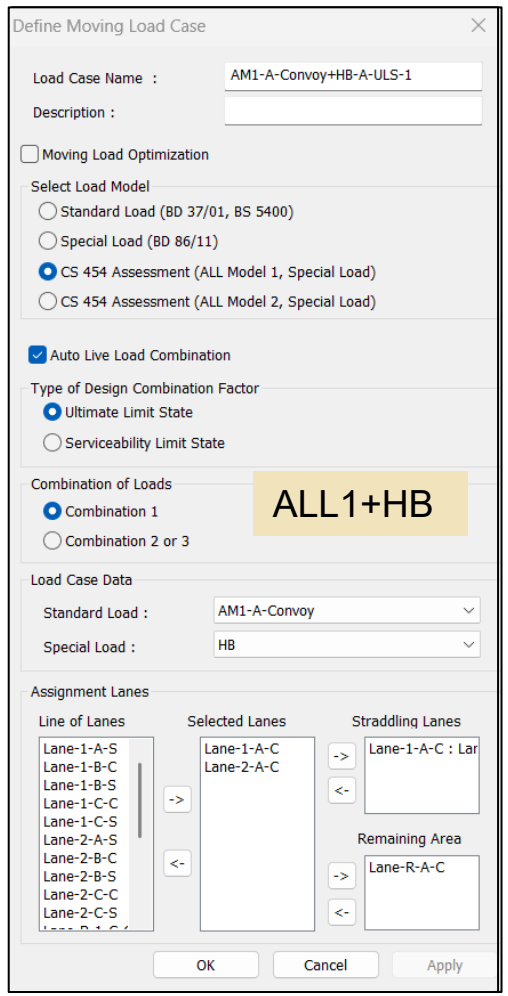
- Auto live load combination for ULS & SLS cases
- Allows various ALL + HB/SV combinations and ALL/SV only too

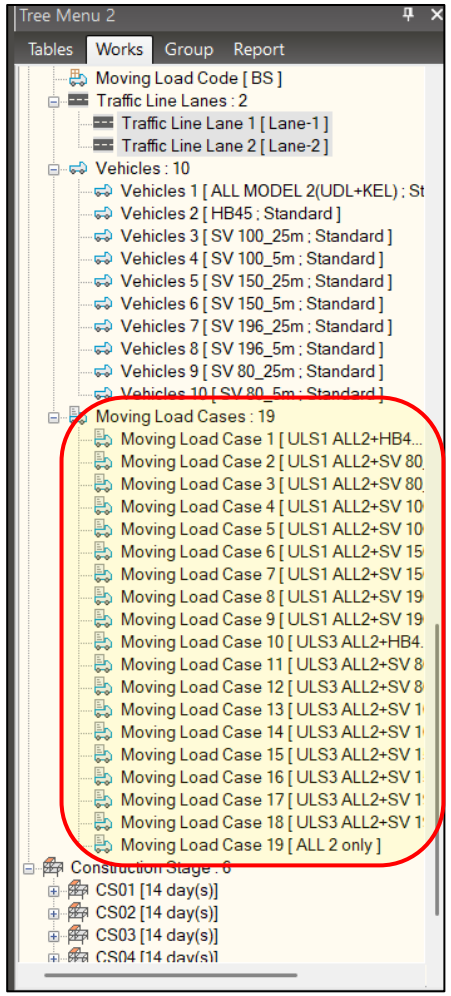




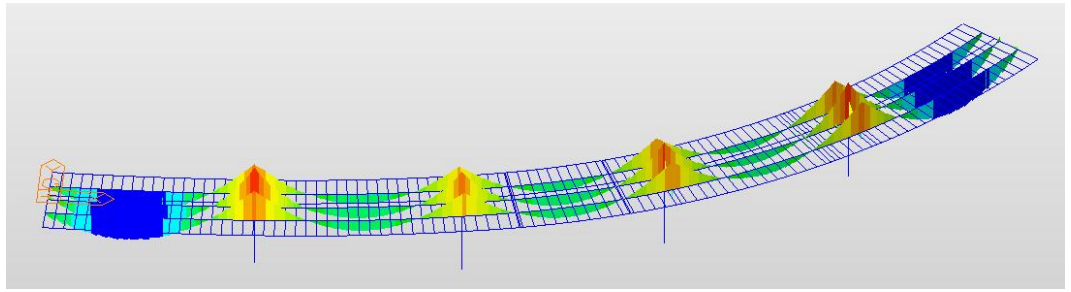


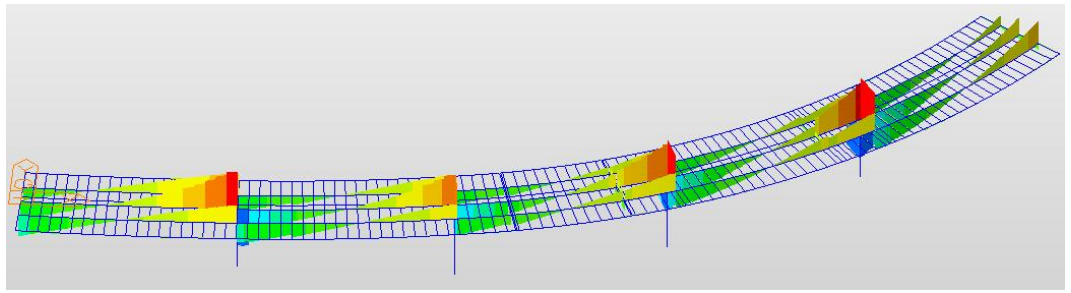


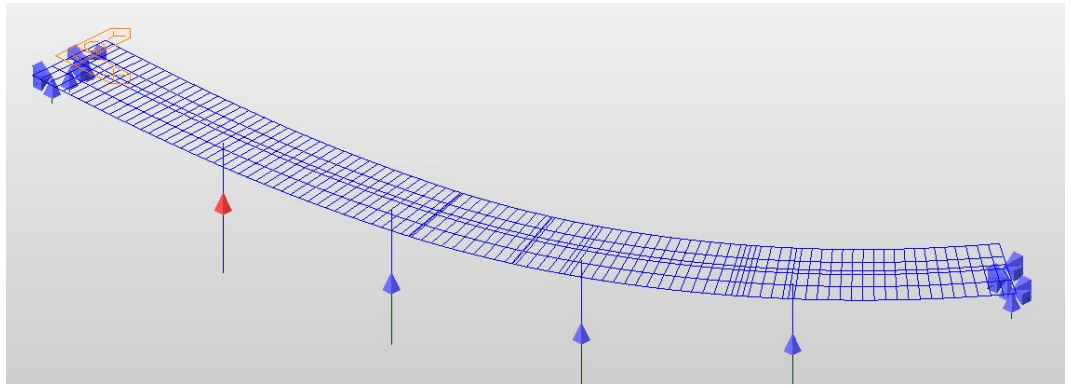




Post-tensioned Concrete Bridge Assessment







Results Extraction & Resistance Calculation

- Deck (As per section 8 & section 5 of CS 455)
  - Flexure
  - Shear
  - Torsion
  - Combined shear & torsion
- Deck Transverse Slab (Section 6 of CS 455)
- Diaphragm (STM as per EC2)
- Pier Column (section 7 of CS 455)
- Half joint (STM as per CS 466)
- Abutment Concrete Hinge (CS 468)
- SLS Stresses (Section 8 of CS 455)

Steel-concrete Composite Bridge Assessment

Steel-Concrete Composite Bridge Assessment

- Three simply supported spans - **steel-concrete composite beam** and slab , spans 1,2,3 approx. 18m, 18m, & 25m
- Steel rolled beams which act compositely with a 250mm deep RC deck slab
- Substructure: **RC abutments and RC pier column portals**
- Intermediate pier column portals are **resting on pot bearings** which are supported on a combined pier footing
- Carries 2 lanes of traffic and a footway on each side

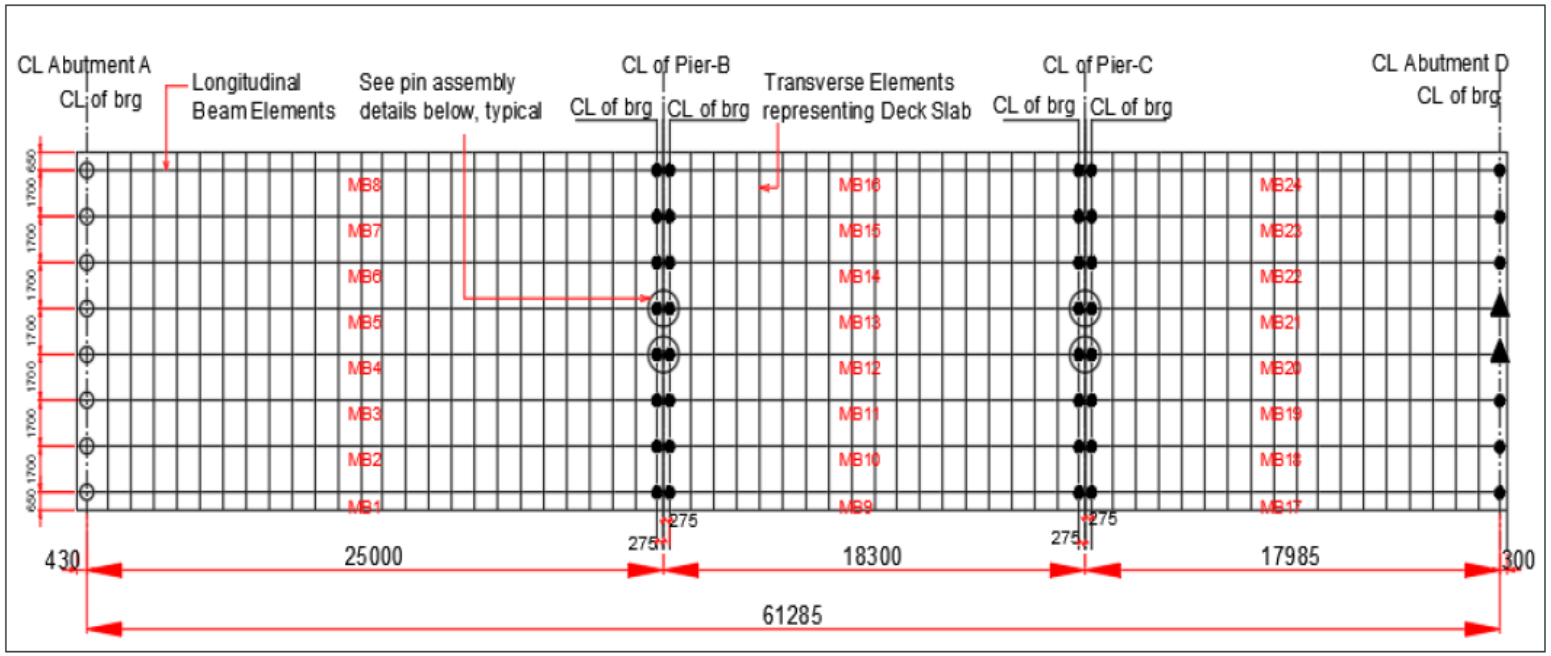
Ref: Google earth imagery

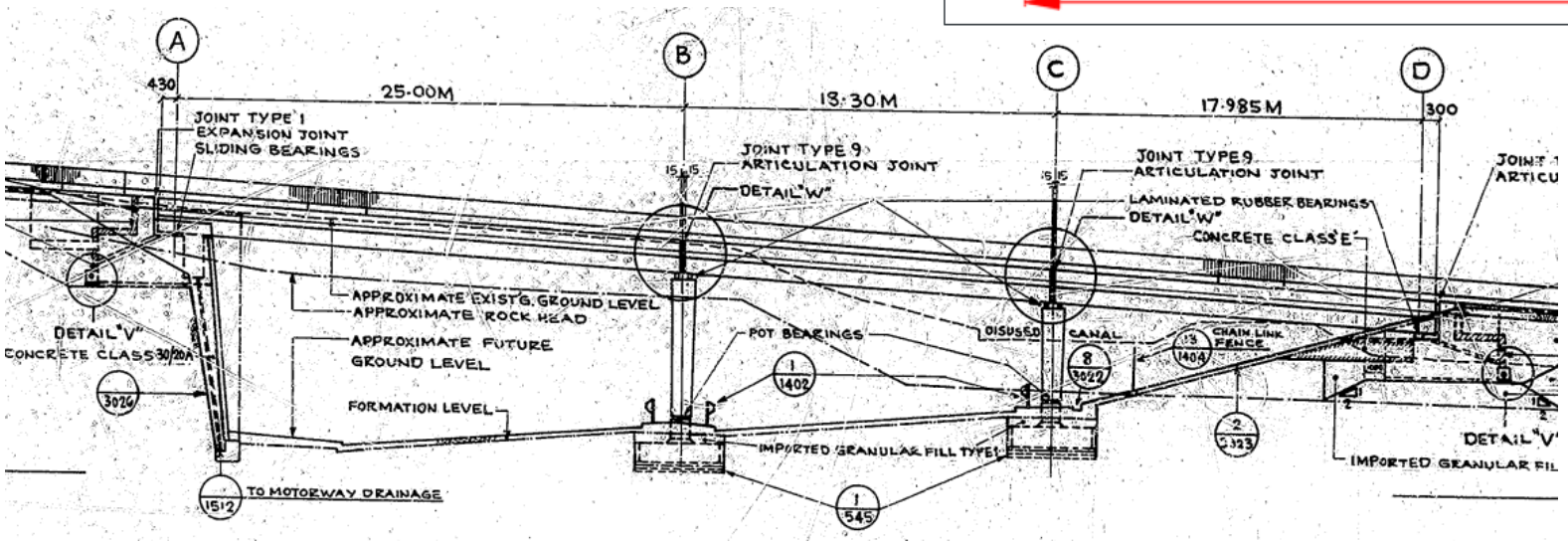
Steel-Concrete Composite Bridge Assessment

General Arrangement

Articulation -

- Abutments- laminated rubber bearings, Sliding bearings
- Piers- laminated rubber bearings
- Internal main beams are connected longitudinally with a pin assembly at piers B & C and at abutment D (South)





(all dimensions are in mm)

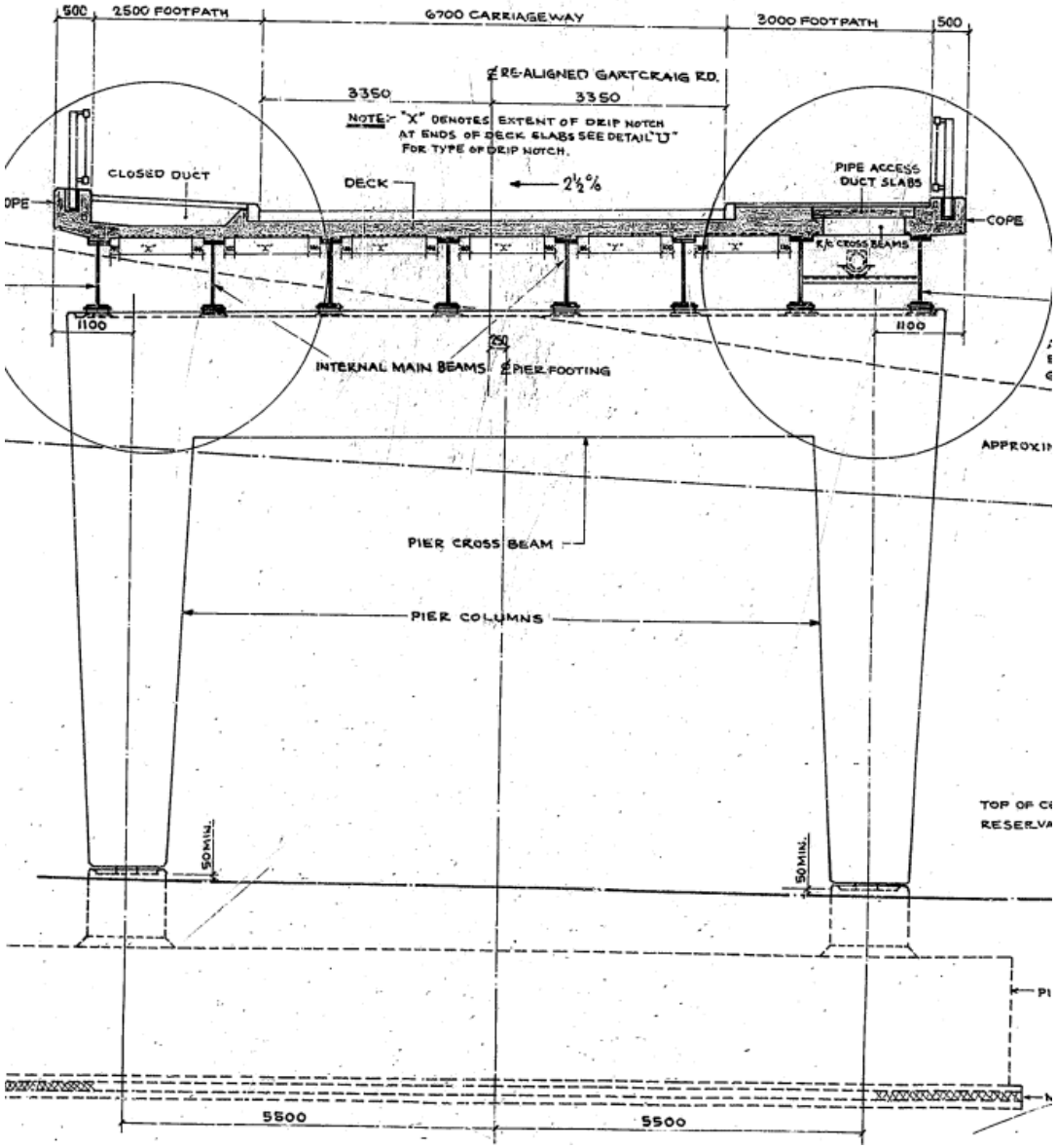
● Free Sliding bearing (Vertical restraint, longitudinal partially restraint*)

○ Free Sliding bearing (only vertical restraint)

▲ All translation DOF restraint, all rotational DOF free

Steel-Concrete Composite Bridge Assessment

General Arrangement

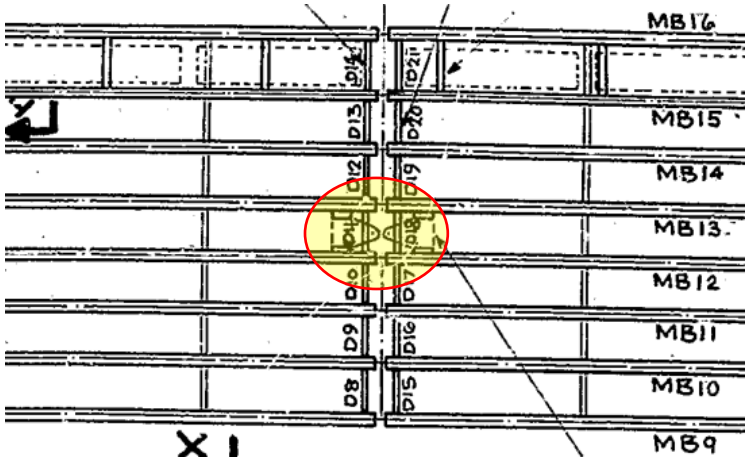


- Bottom of Pier column B & C - Pot bearings

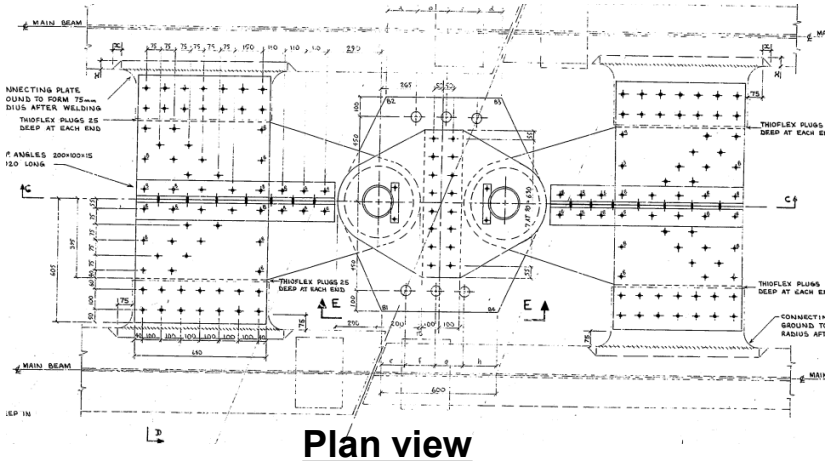
Steel-Concrete Composite Bridge Assessment

General Arrangement

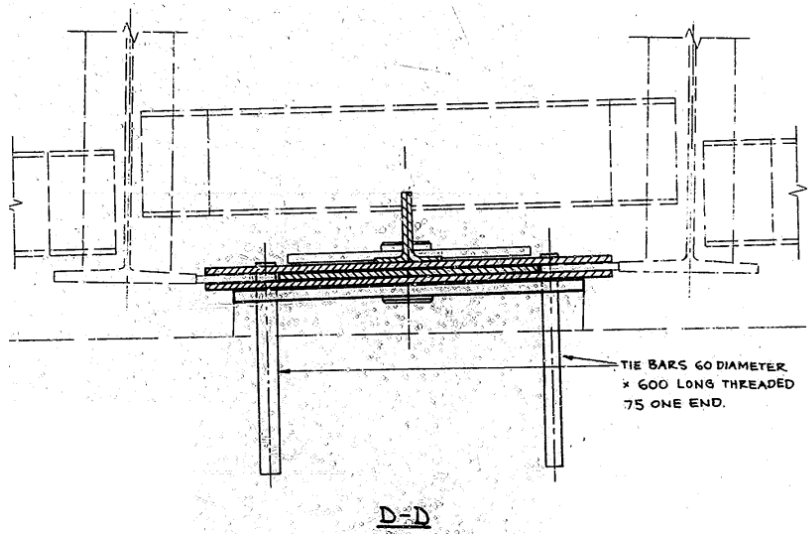
- Pier Pin Assembly
  - Link between girder ends (all translation restraint)
  - Link between girder end & pier cross beam (all translation restraint)



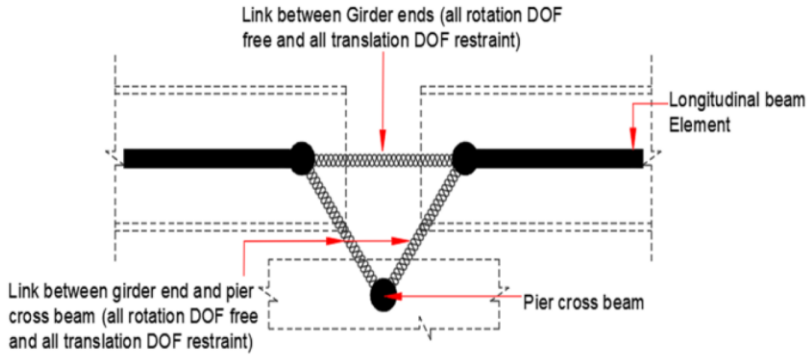
Plan view



Plan view



Cross section



Idealized diagram for Pin Assembly

Side Elevation

Steel-Concrete Composite Bridge Assessment

Assessment Scope:

- Beams, shear studs, deck slab – CS 455 CS 456, CS 457
- Piers- CS 453

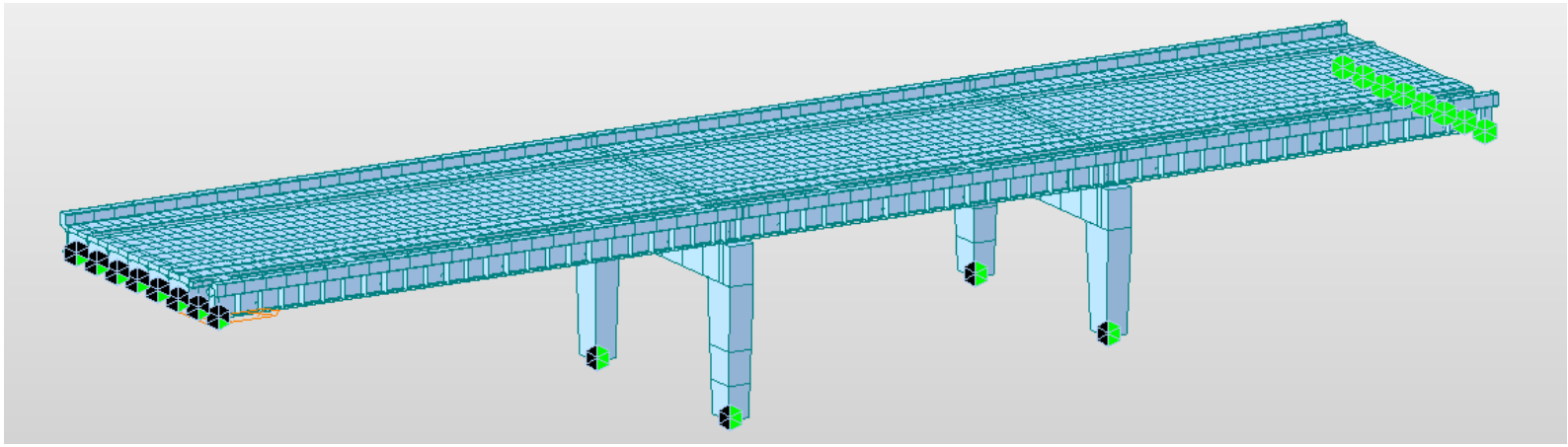
Actions:

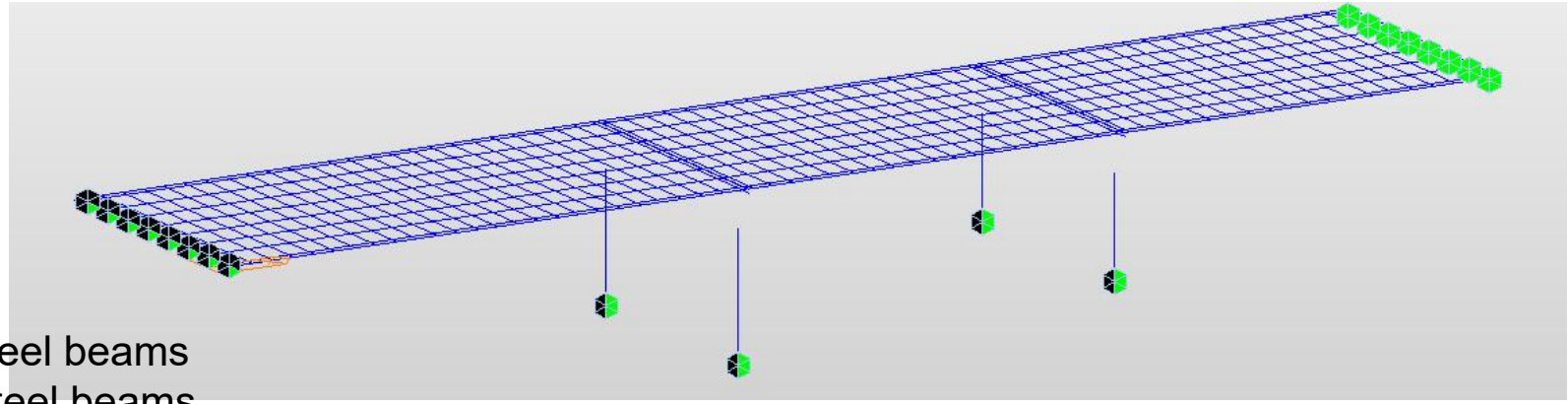
- Permanent loads, SIDL, Thermal
- Snow/Wind (ignored)
- Live Load – ALL model 1, 45HB, SV loadings

Structural Analysis:

- 2D linear elastic grillage global model
- ULS & SLS verifications
- Include original construction staging

Bridge Grillage Model





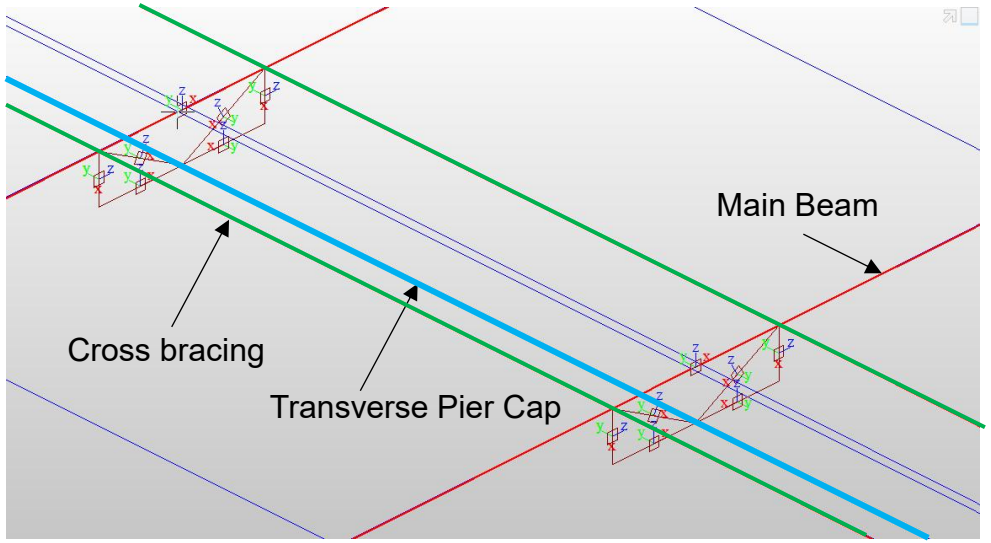
- Longitudinal members aligned with main steel beams
- Transverse members orthogonal to main steel beams
- Diaphragms, cross beams
- Staged construction
- Boundary conditions as per AIP
- Load Application as per AIP

Steel-Concrete Composite Bridge Assessment

Connection Details

Pier Pin Assembly

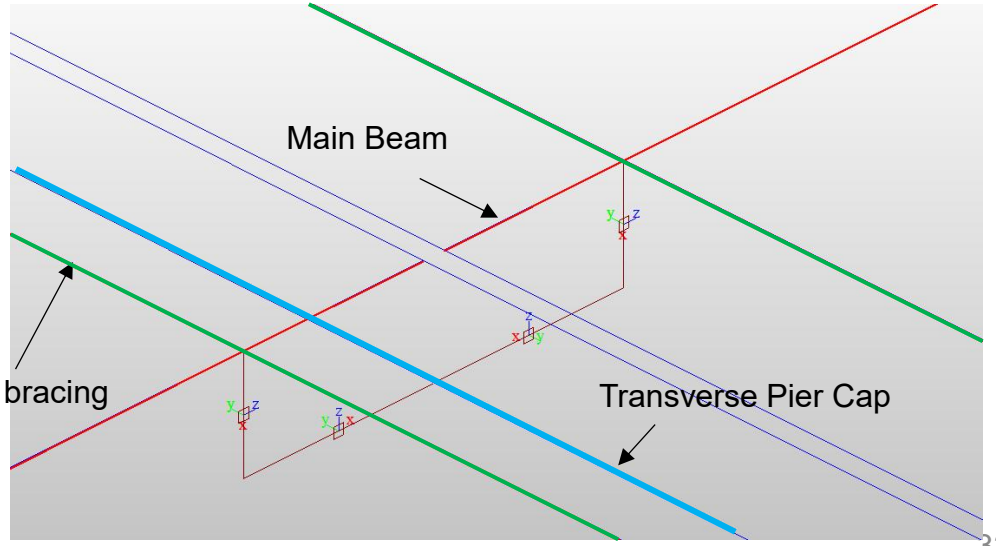
Link between girder ends (all translation restraint)
Link between girder end & pier cross beam (all translation restraint)



Modelling of pier pin assembly

Rubber Bearing Pad

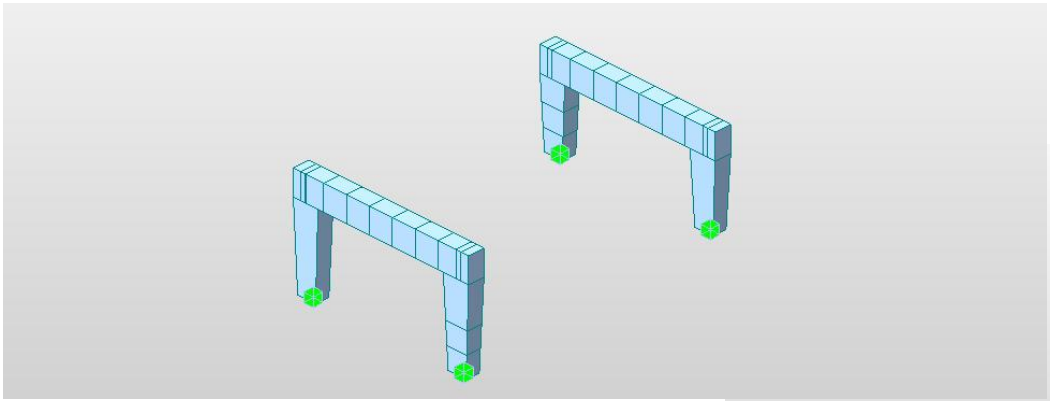
Restraint against translation for laminated rubber bearing pads based on the shear rating of the bearing pads

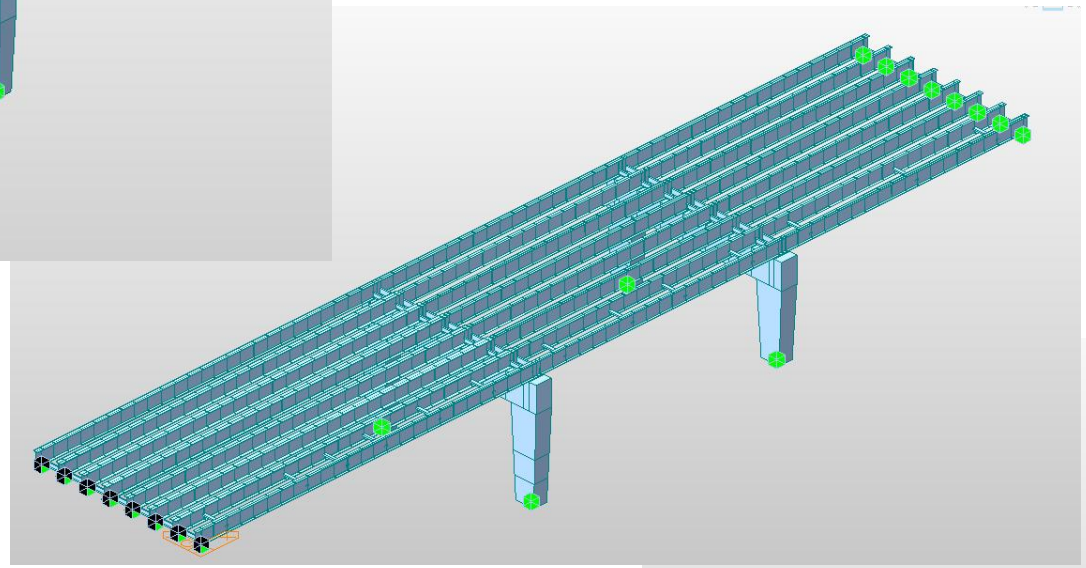


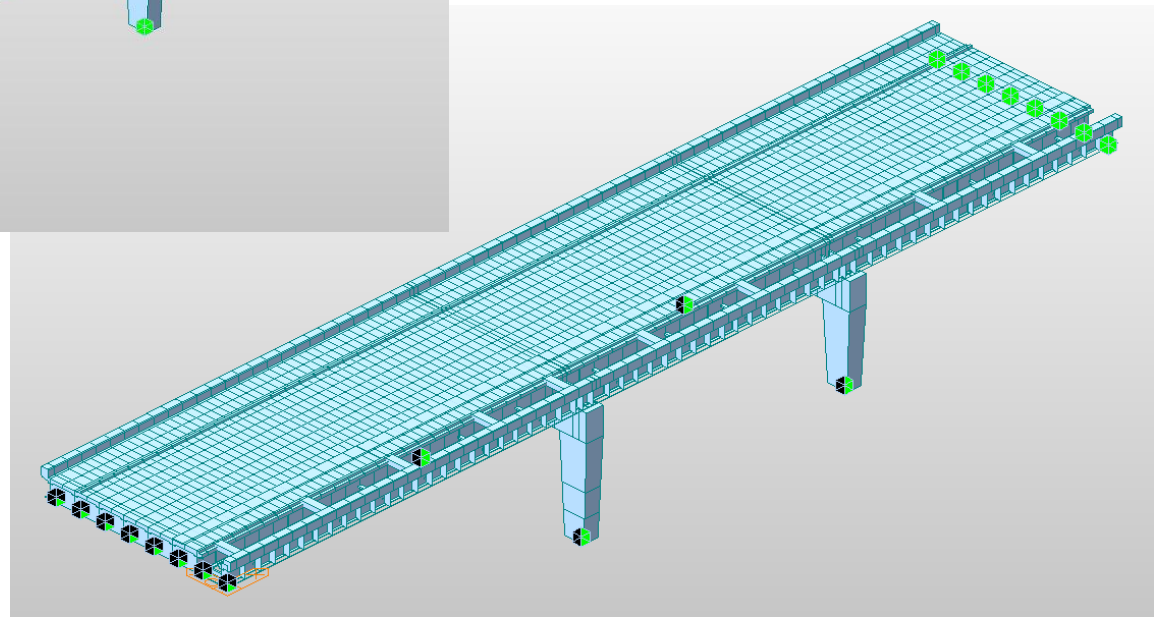
Modelling of laminated rubber bearing with stiffness

Steel-Concrete Composite Bridge Assessment

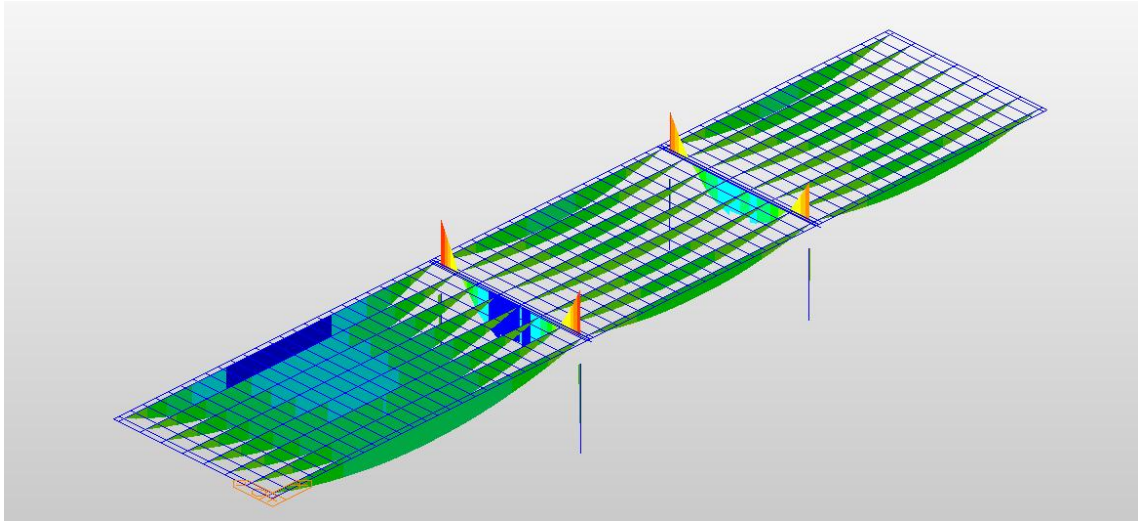
Construction Stages

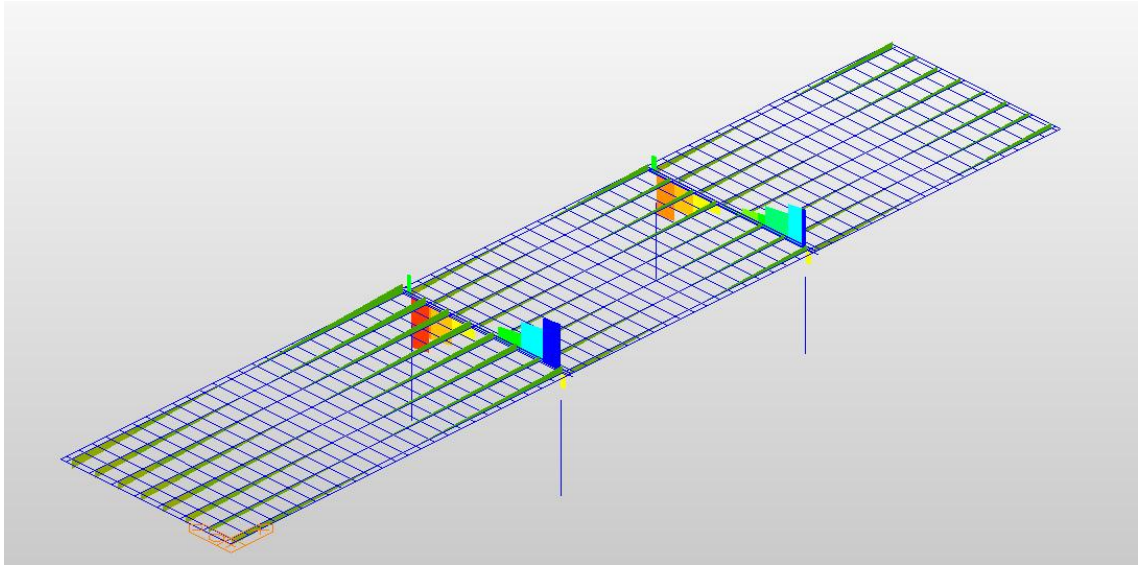






Steel-Concrete Composite Bridge Assessment





Results Extraction & Resistance Calculation

- Steel Members (CS 456 & CS 457), Refers to BS 5400-3
  - Steel Composite Beams
  - Shear Stud
  - Steel Diaphragm
  - Steel Cross Beam
- RC Deck Transverse Slab (CS 455)
- RC Pier Column (CS 455)
- RC Pier Cap (CS 455)


Thank you