# Highway 401 Cornwall Centre Road Overpass

## Rapid Bridge Replacement

## GWP 4029-08-00

**Presentation on Methodology of Rapid Bridge Replacement For a Concrete Rigid Frame Structure**

April 2016

Ontario

MMM GROUP

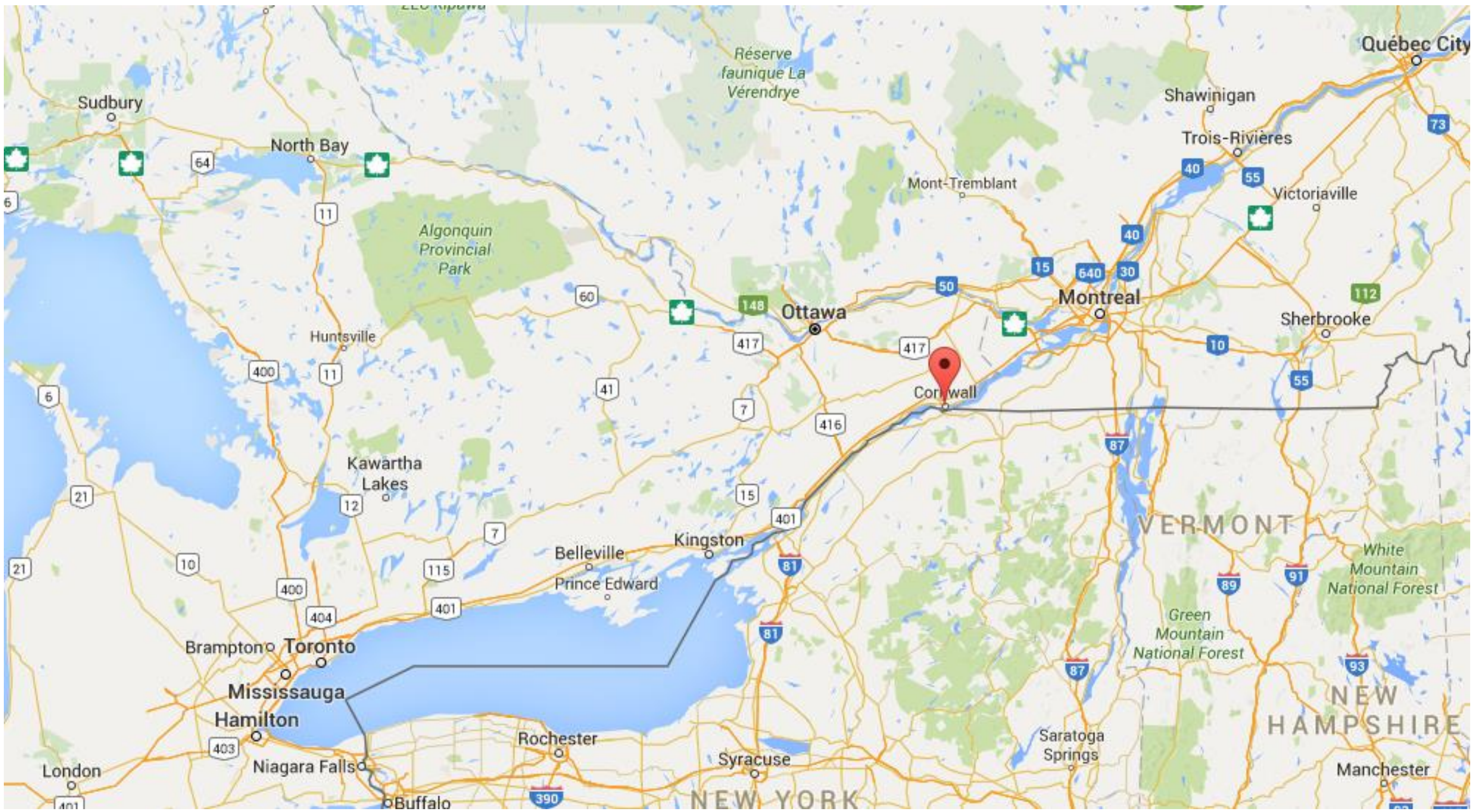
# PRESENTATION OVERVIEW

MMM GROUP

- BACKGROUND
- WEST BOUND LANE – SEGMENTAL APPROACH
- EAST BOUND LANE – SINGLE PIECE WITH FOOTINGS
- LESSONS LEARNED

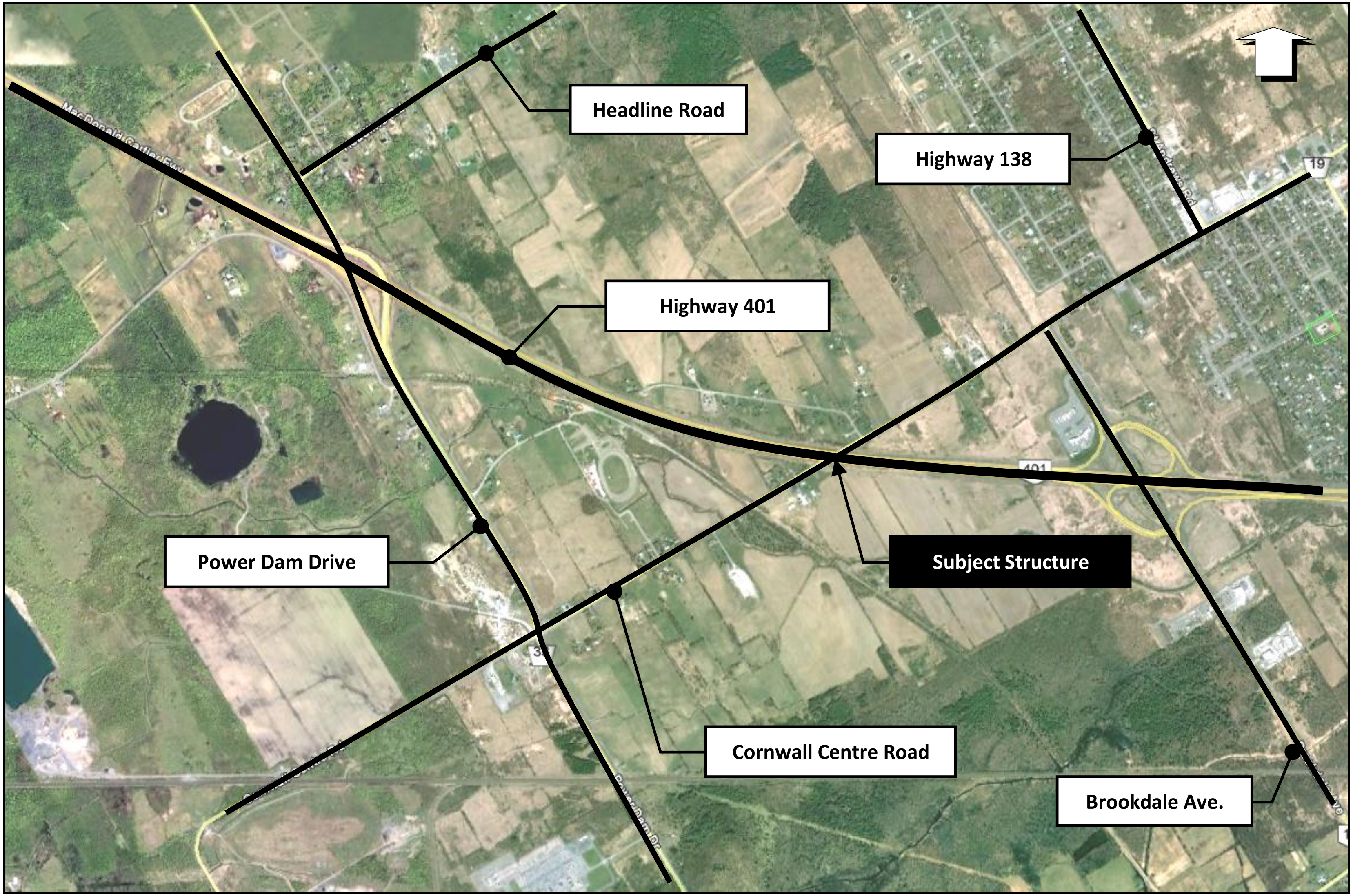
# BACKGROUND

- Location
- History
- Design Criteria

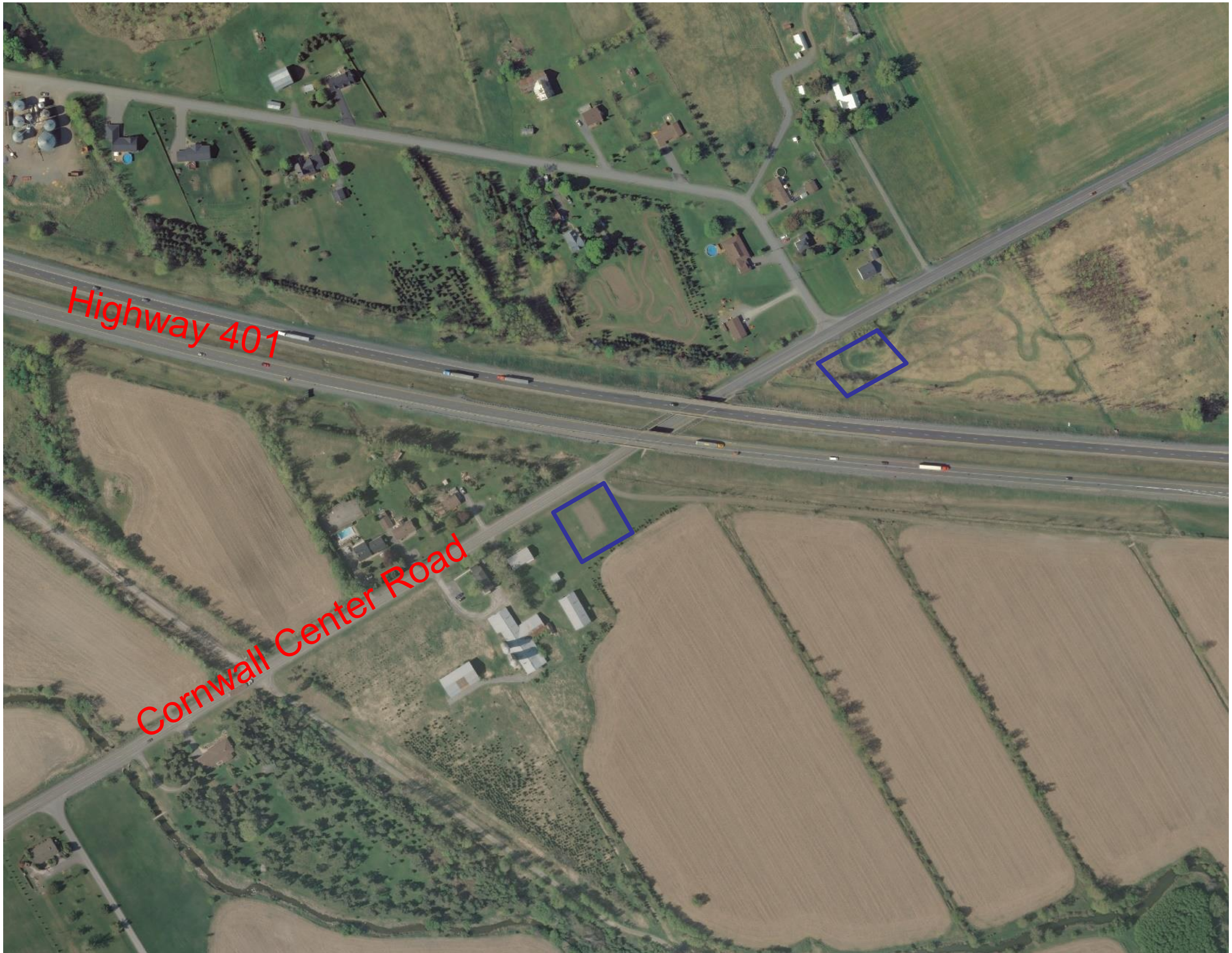


# LOCATION

MMM GROUP



# LOCATION



# EXISTING STRUCTURE

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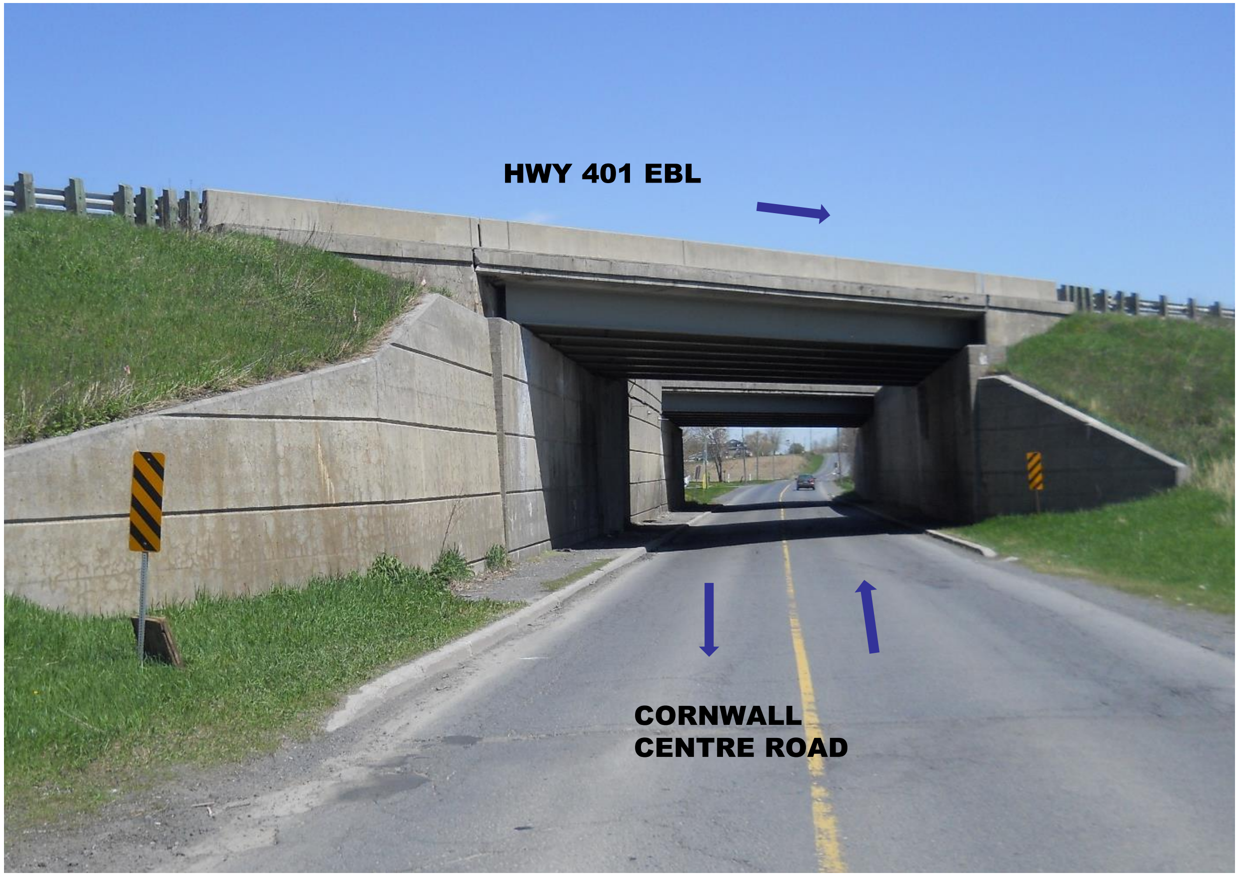
**MEDIAN RETAINING WALL**

# EXISTING STRUCTURE



# GENERAL HISTORY

- Original twin structures built in 1962
- Single span steel girder with composite concrete deck superstructures
- Conventional concrete abutments on spread footings
- 51.5° skew
- West median retaining wall leaning
- West median retaining wall tied back to deadman  anchor in 2009
- Decision made to replace in 2011 following EA

# DESIGN CRITERIA

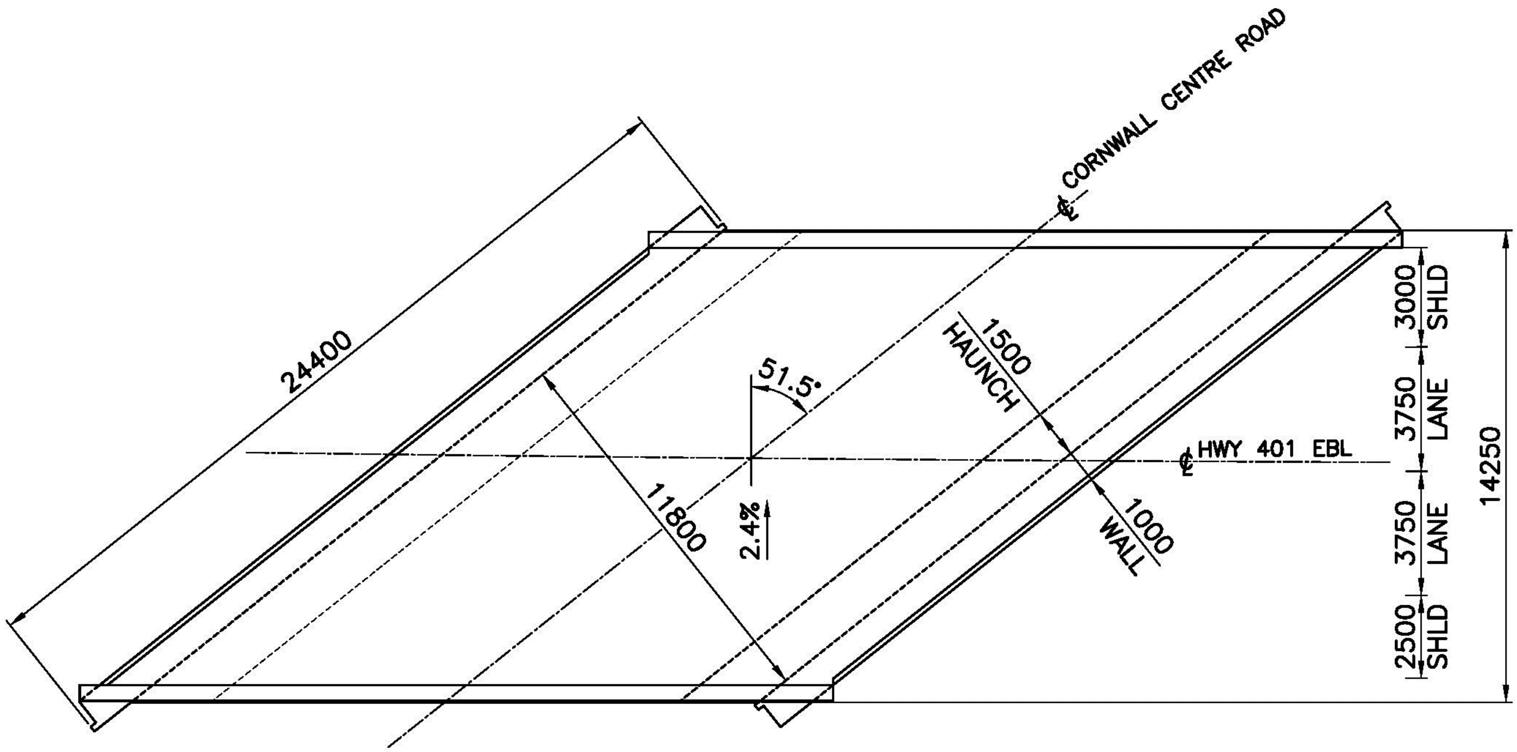
- **Highway 401**
  - 2.5m Left Shoulder
  - Two 3.75m Lanes
  - 3.0m Right Shoulder
  - PL-3 (TL-5) Concrete Barriers
  - 51.5° skew
  - 600m horizontal radius
  - 2.4% superelevation
  - AADT = 23,000
  - 48% Trucks
  - Peak VPH = 3300

# DESIGN CRITERIA

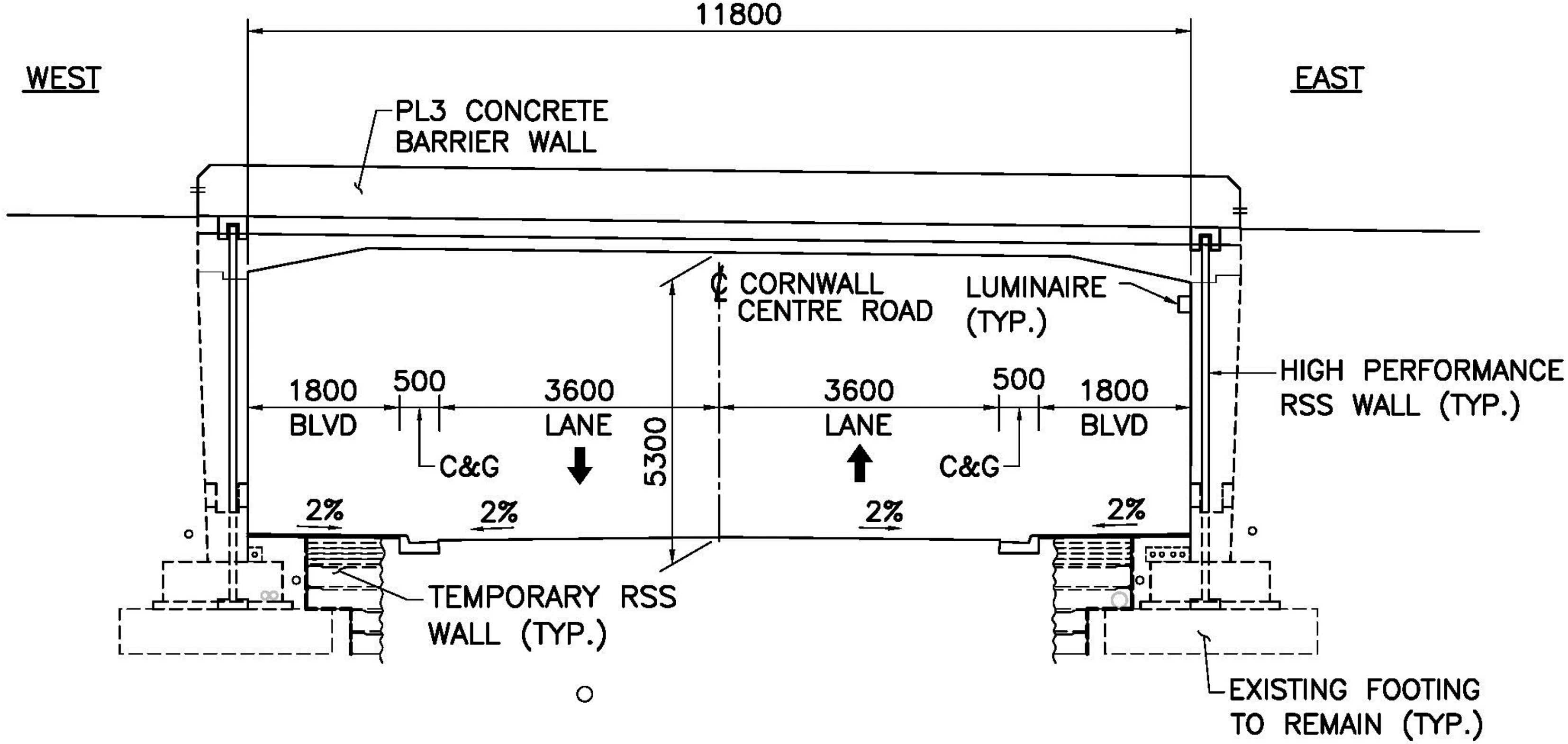
- **Cornwall Centre Road**
  - 1.8m multi-use path
  - 0.5m Curb and Gutter
  - 3.6m SBL
  - 3.6m NBL
  - 0.5m Curb and Gutter
  - 1.8m multi-use path
  - Sag profile (lowest point at WBL)

* Original road had sidewalk on one side only. Shift in centerline to accommodate new symmetrical section.

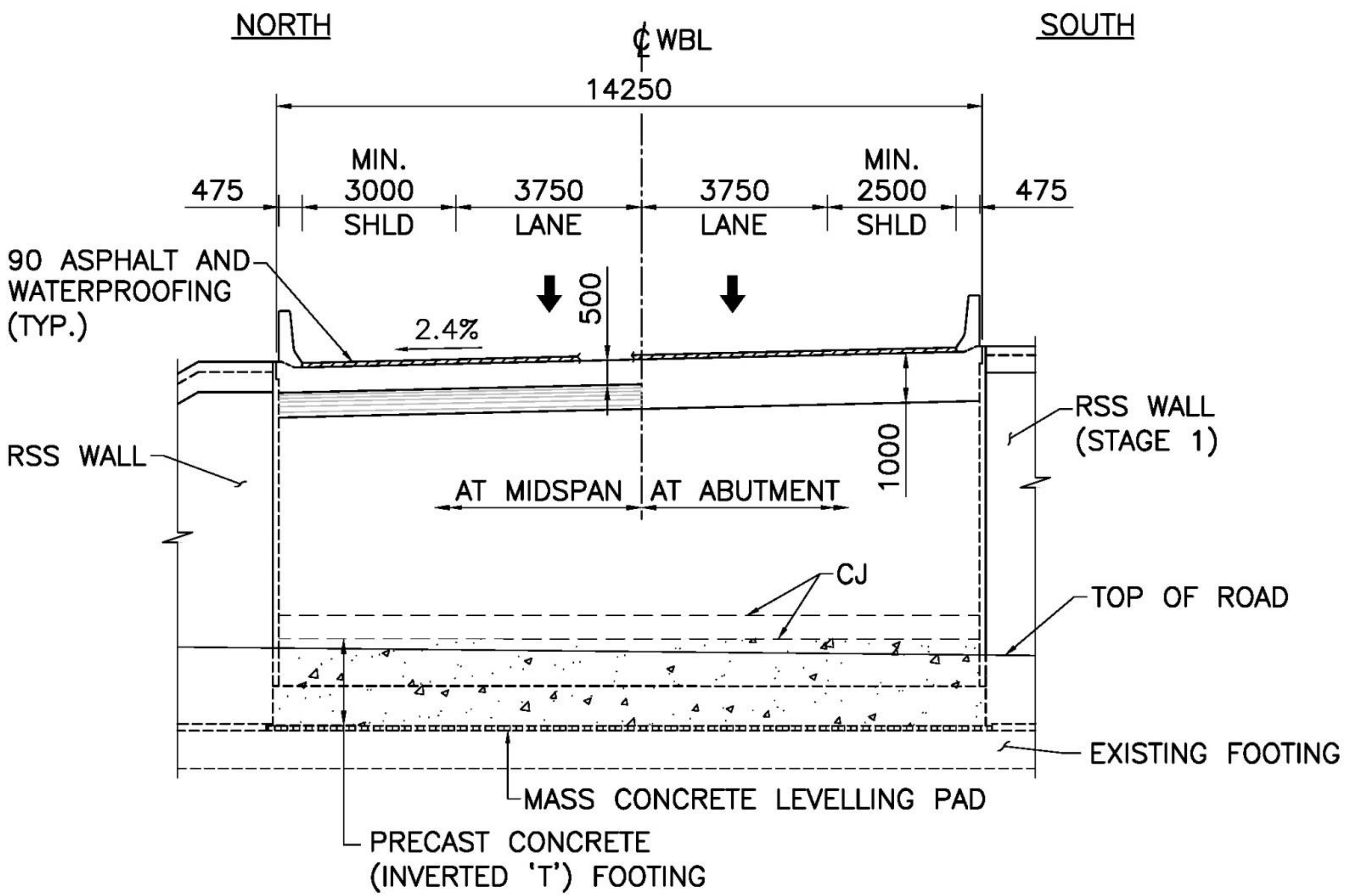
# CONFIGURATION



# CONFIGURATION



# CONFIGURATION




PRECAST CONCRETE RIGID FRAME

# PRESENTATION OVERVIEW

- **WEST BOUND LANE – SEGMENTAL APPROACH**
  - Engineering Challenges
  - RBR Configuration for *Footing* Move
  - RBR Configuration for *Rigid Frame* Move

# WBL COMPONENTS
# TWO FOOTINGS + TOP RIGID FRAME

# WBL ENGINEERING CHALLENGES

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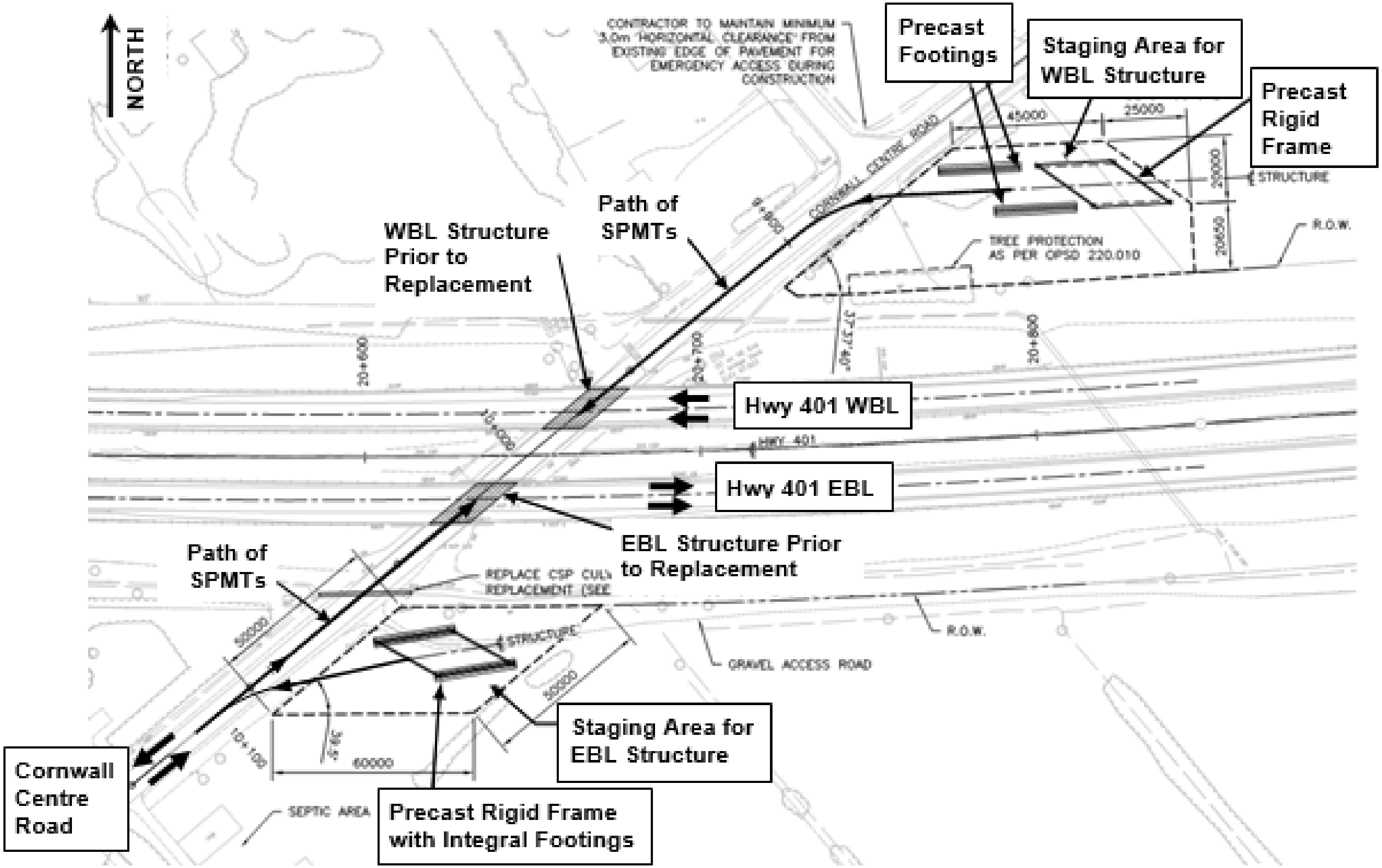
- Heavy Load (1100 tonnes top RF piece)
- Load concentrated at obtuse corners
- Short structure span limits space for SPMT's
- Legs deflect outward when lifted
- Road profile sag curve set maximum length of SPMT train (could not lower road)
- Lateral earth pressure due to heavy axle loads higher than friction at underside of footing
- How to construct joint / tolerances (24 m long mating section)

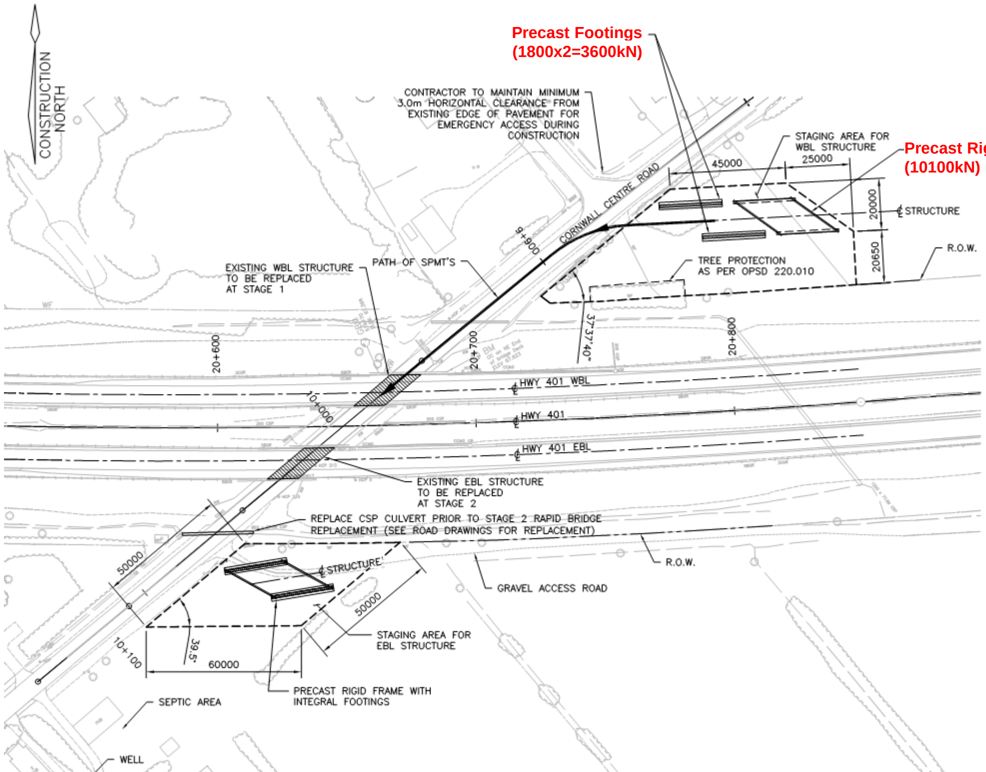
# TRANSPORT ROUTES



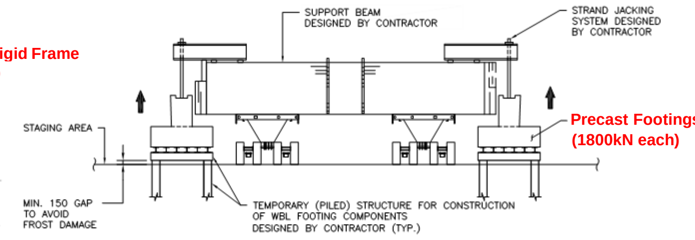
# WBL MEDIAN CROSS-OVER

# WBL MEDIAN CROSS-OVER

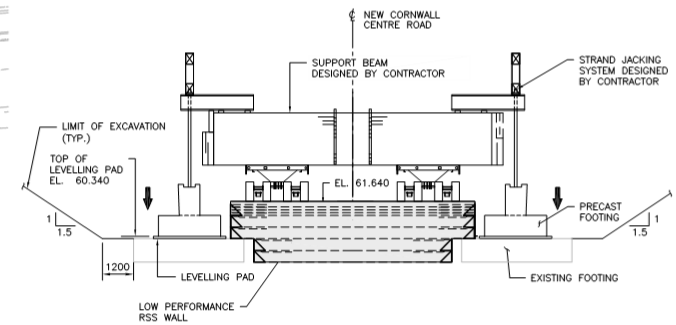
# WBL STAGED CONSTRUCTION



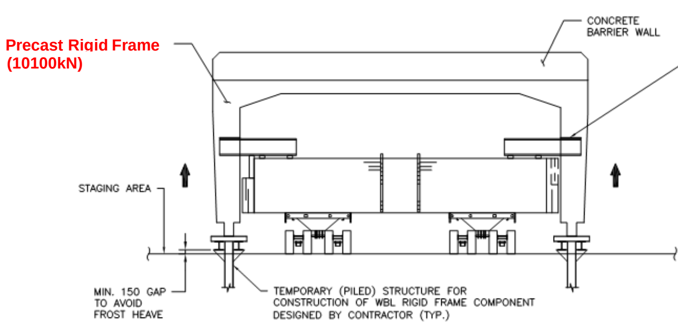

PLAN
1:1000



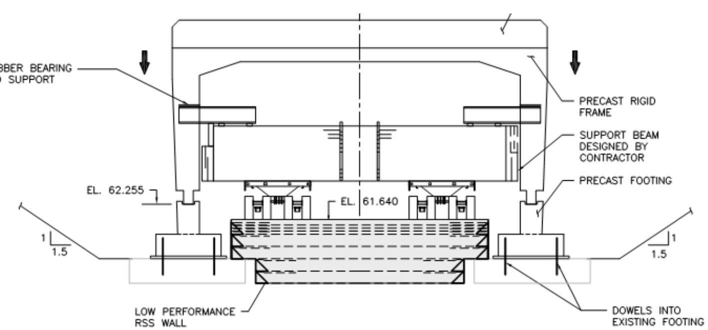

STAGE A – AT STAGING AREA
N.T.S.




STAGE A – AT FINAL LOCATION
N.T.S.

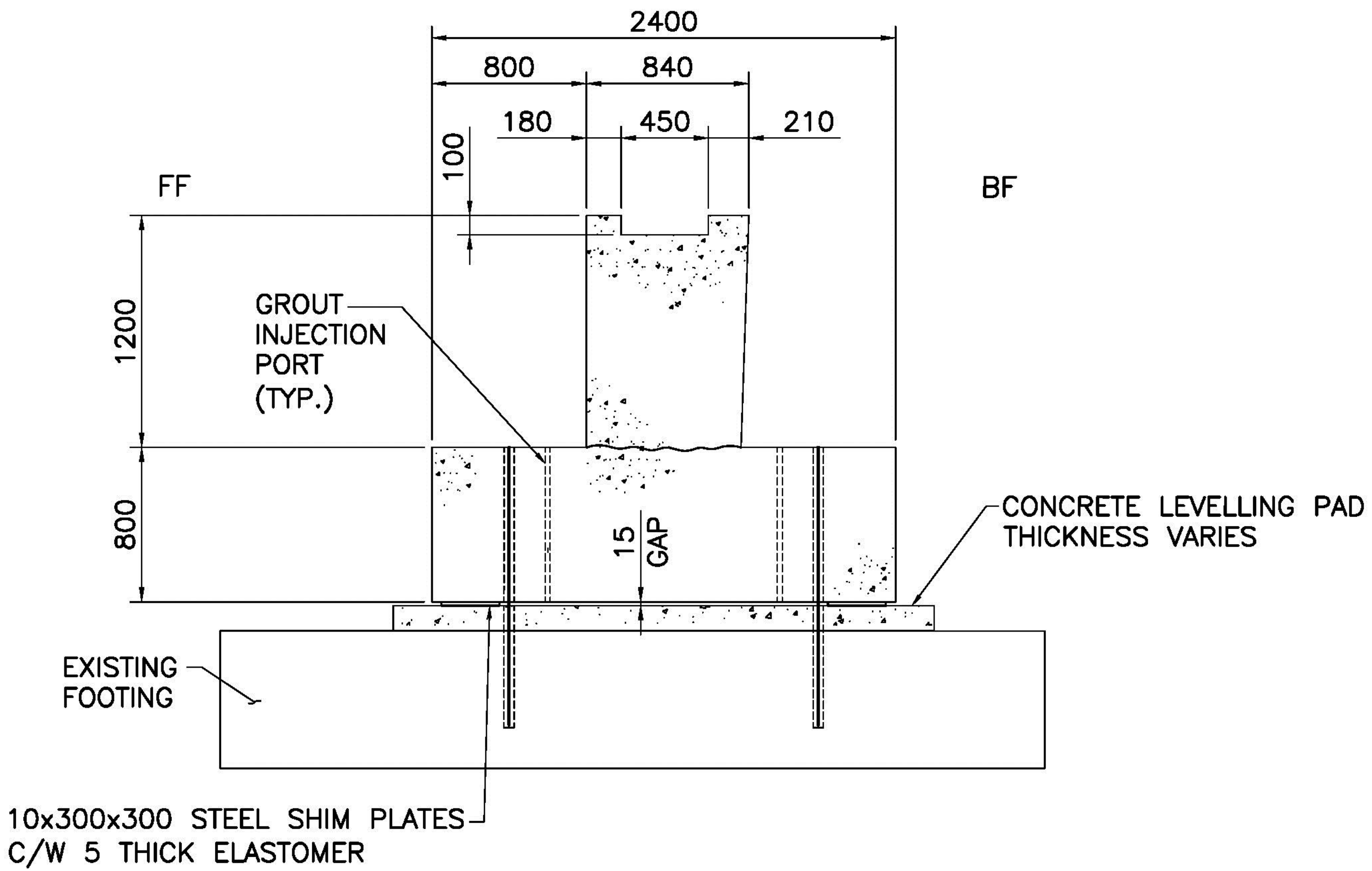



STAGE B – AT STAGING AREA
N.T.S.




STAGE B – AT FINAL LOCATION
N.T.S.

# WBL FOOTING



2400
800
840
180
450
210
100
FF
BF
1200
GROUT INJECTION PORT (TYP.)
800
15 GAP
CONCRETE LEVELLING PAD THICKNESS VARIES
EXISTING FOOTING
10x300x300 STEEL SHIM PLATES C/W 5 THICK ELASTOMER

# WBL  FOOTING MOVE

MMM GROUP

# WBL  FOOTING MOVE

# WBL FOOTING MOVE

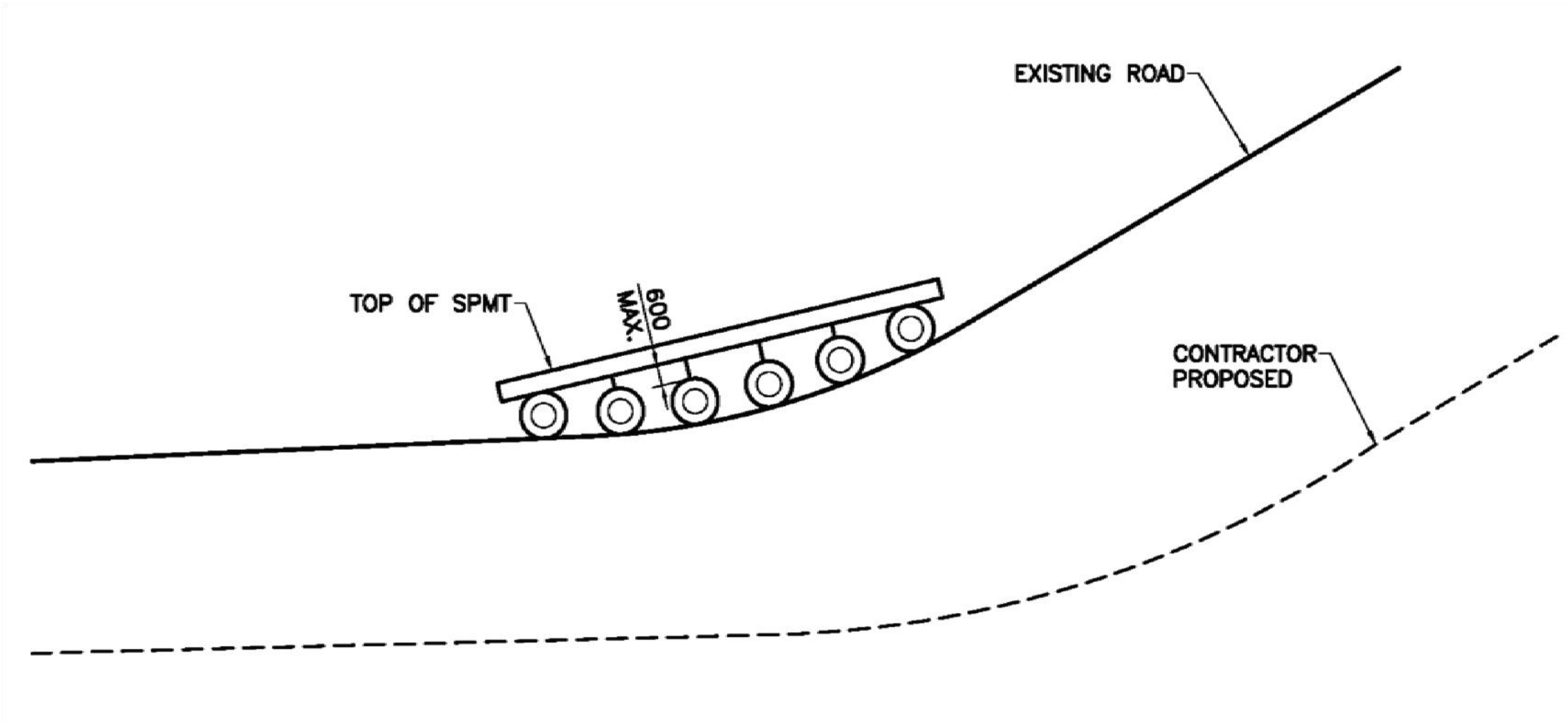
# WBL FOOTING MOVE

MMM GROUP

# WBL TEMPORARY FOUNDATION AT STAGING AREA

MMM GROUP

# SPMT GRADE CHANGE LIMIT



# WBL RF MOVE

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# WBL  RF MOVE

# WBL  RIGID FRAME MOVE


**Note:**    **Dywidag Bars to restrain twist**

# WBL RIGID FRAME MOVE

# WBL RF MOVE

MMM GROUP

# WBL RF MOVE

# WBL RF MOVE

MMM GROUP

# WBL RF MOVE

MMM GROUP

# WBL  RF MOVE

# WBL RF MOVE

MMM GROUP

# WBL  COMPLETED JOINT

MMM GROUP

# WBL – MODELING & ANALYSIS

MMM GROUP

## Structural Modeling

- *Software:* CSiBridge Commercial Finite Element Analysis (ver.14)
- *Elements:* Concrete Rigid Frame – 4-node quadrilateral shell element
  Lifting System – 2-node beam element

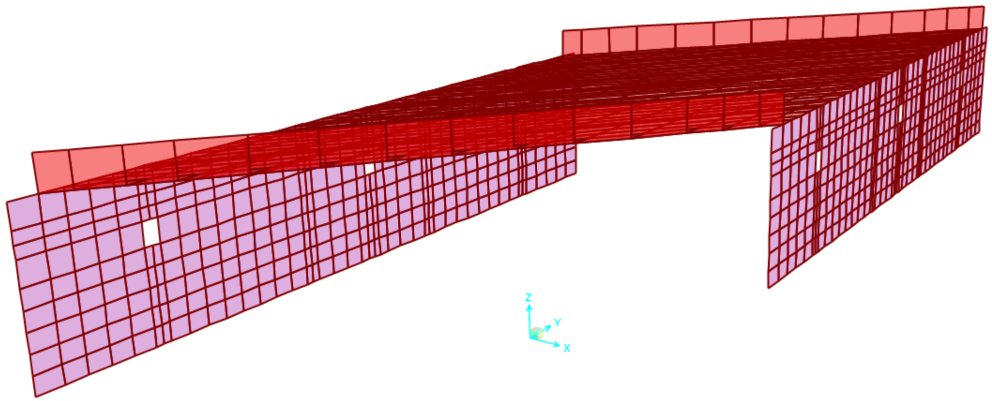
| **Member** | **Lifting System Section Properties** | | | |
|---|---|---|---|---|
| | EBL | | WBL | |
| | I ($m^4$) | A ($m^2$) | I ($m^4$) | A ($m^2$) |
| SPMT | $1.298 \times 10^{-2}$ | 0.491 | $1.298 \times 10^{-2}$ | 0.491 |
| Lifting Beam | $1.615 \times 10^{-3}$ | 0.037 | - | - |
| Jacking Tower | $8.166 \times 10^{-3}$ | 0.075 | - | - |
| Connecting Beam | $7.991 \times 10^{-2}$ | 0.136 | $7.991 \times 10^{-2}$ | 0.136 |

- *Loading:* Equal vertical force was applied to every SPMT axle location.
  Total load applied to the axles is equal to the total weight of the concrete structure and the lifting system
- *Boundary conditions:* Fictitious boundary conditions at center of deck and lifting system for modeling stability (zero reactions)

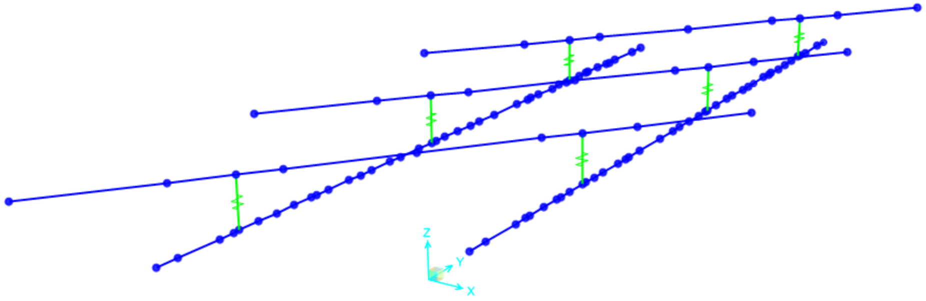
# WBL – MODELING & ANALYSIS

MMM GROUP

## Structural Modeling



Concrete Rigid Frame Modeling – Shell Element

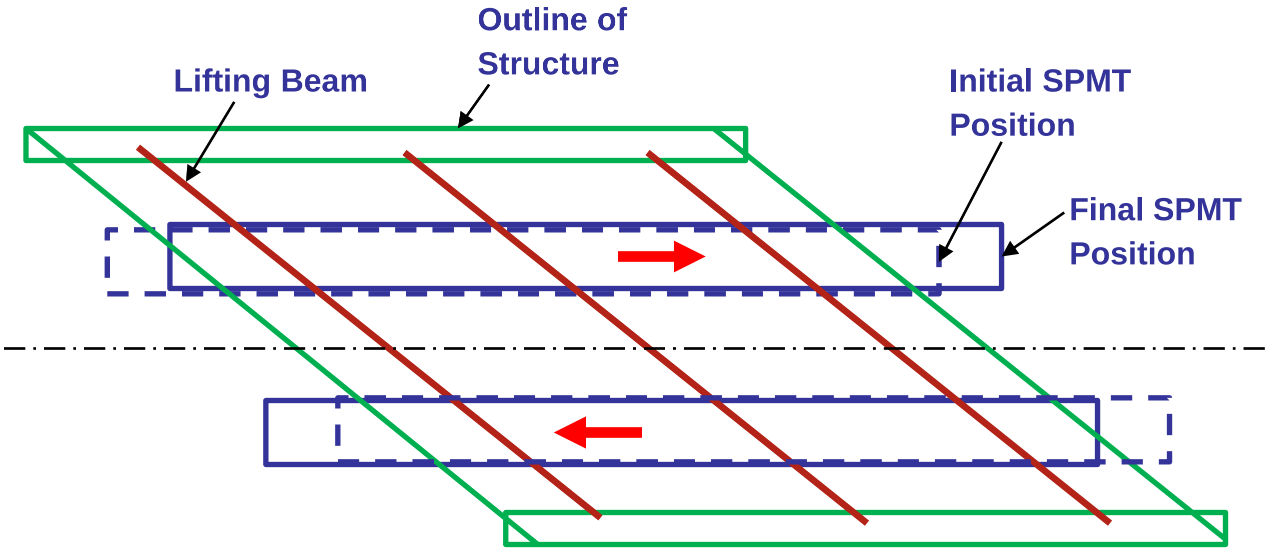


Transport System Modeling – Beam Element

# WBL – MODELING & ANALYSIS

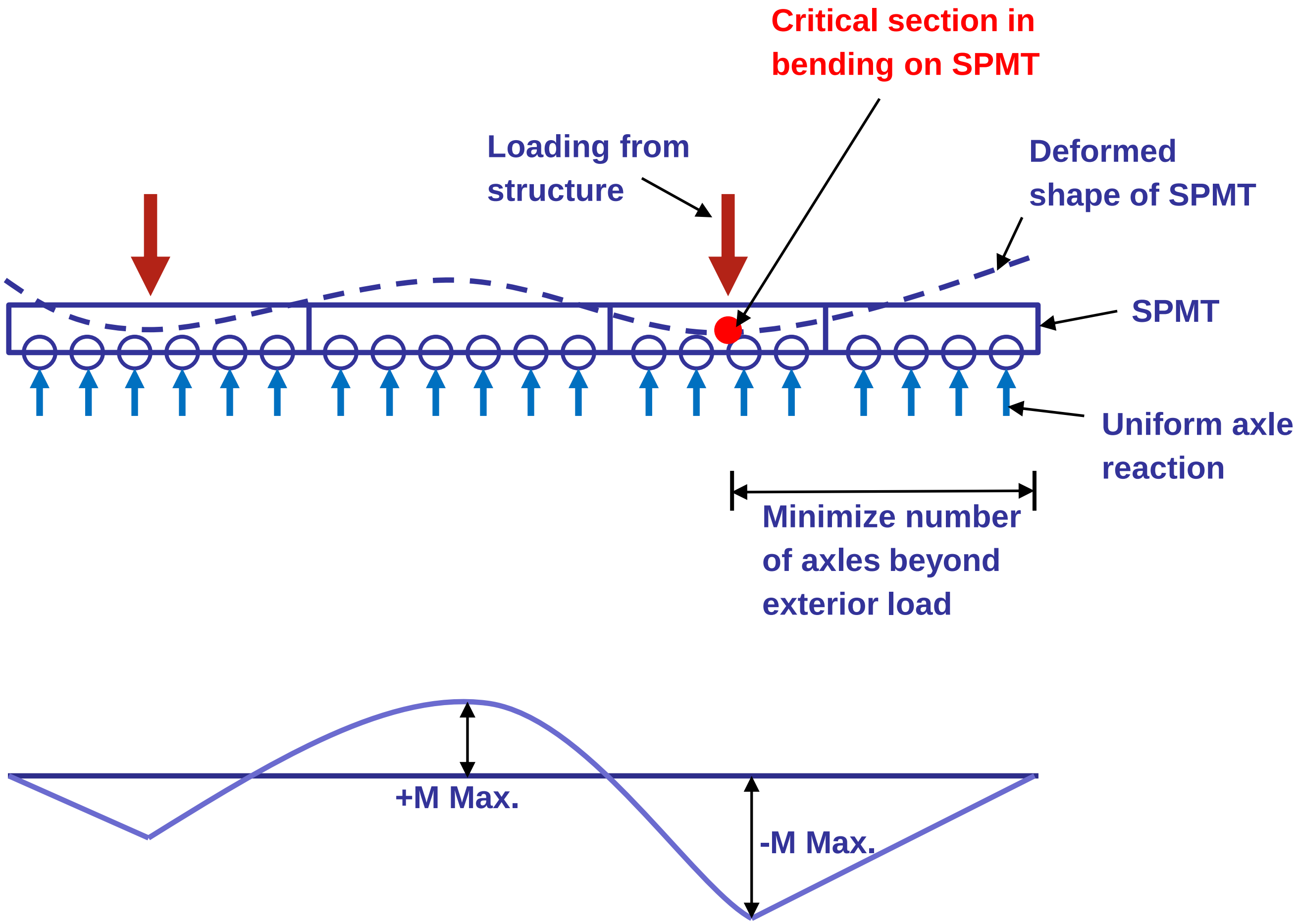
## Positioning of SPMT

- Place more axles of SPMT at obtuse corners to take more load from structure and to avoid excessive distortion (twisting) of the structure



# LIFTING SYSTEM

## SPMT Configuration



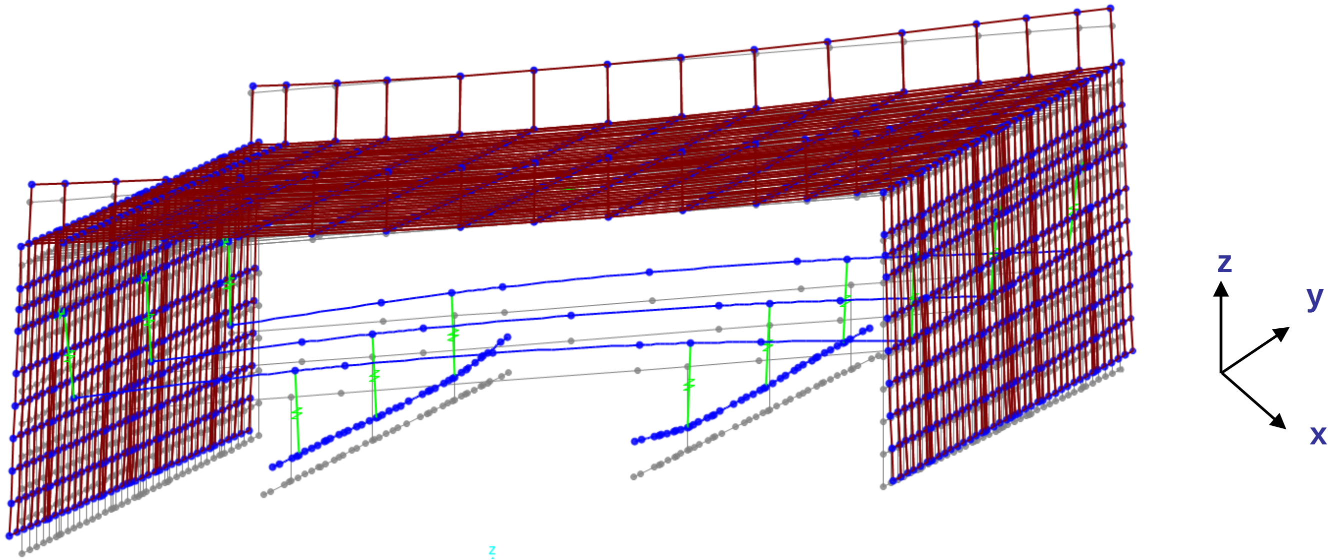
# WBL – Results

## Reactions at Block-outs

| Location | Reactions | |
|---|---|---|
| | Flexible | Infinite Stiffness |
| Block-out 1 (Obtuse corner) | 1954 kN | 2400 kN |
| Block-out 2 | 1545 kN | 1250 kN |
| Block-out 3 (Acute corner) | 1557 kN | 1400 kN |

# WBL – Results

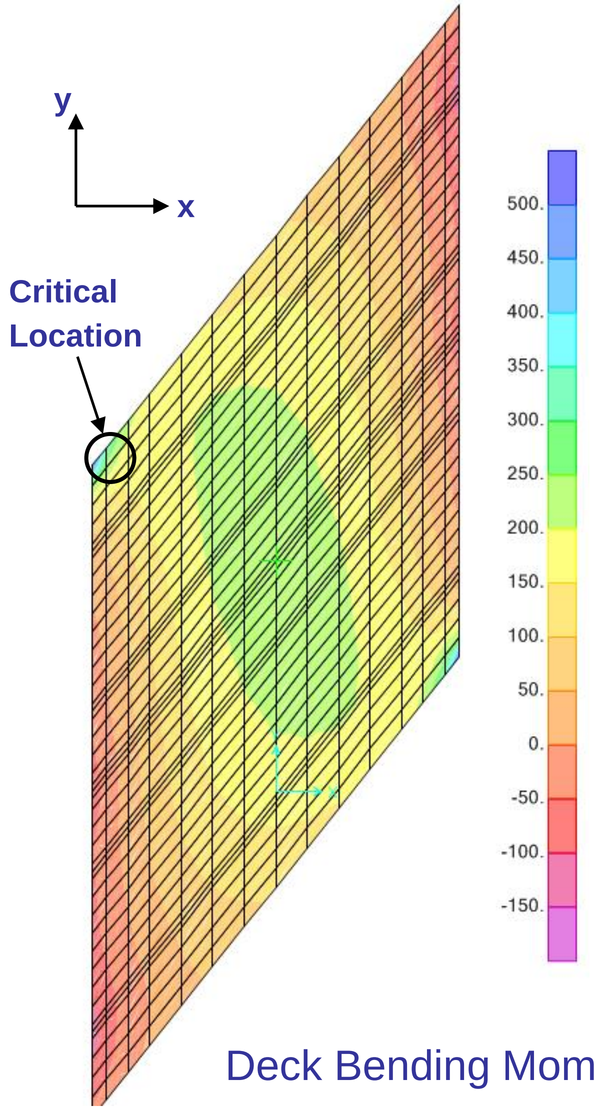
## Deformations




| Location | Displacements (mm) | | |
|---|---|---|---|
| | x (perpendicular to centreline of CCR) | y (parallel to centreline of CCR) | z (vertical direction) |
| Deck – Centre (Base Point) | 0 | 0 | 0 |
| Deck – Obtuse Corner | 0 | 0 | 10.8 |
| Deck – Acute Corner | 1.3 | -0.2 | 31.9 |
| Wall Base – Obtuse Corner | 16.6 | 4.6 | 10.1 |
| Wall Base – Acute Corner | 21.6 | 4.7 | 32.7 |

# WBL – Results

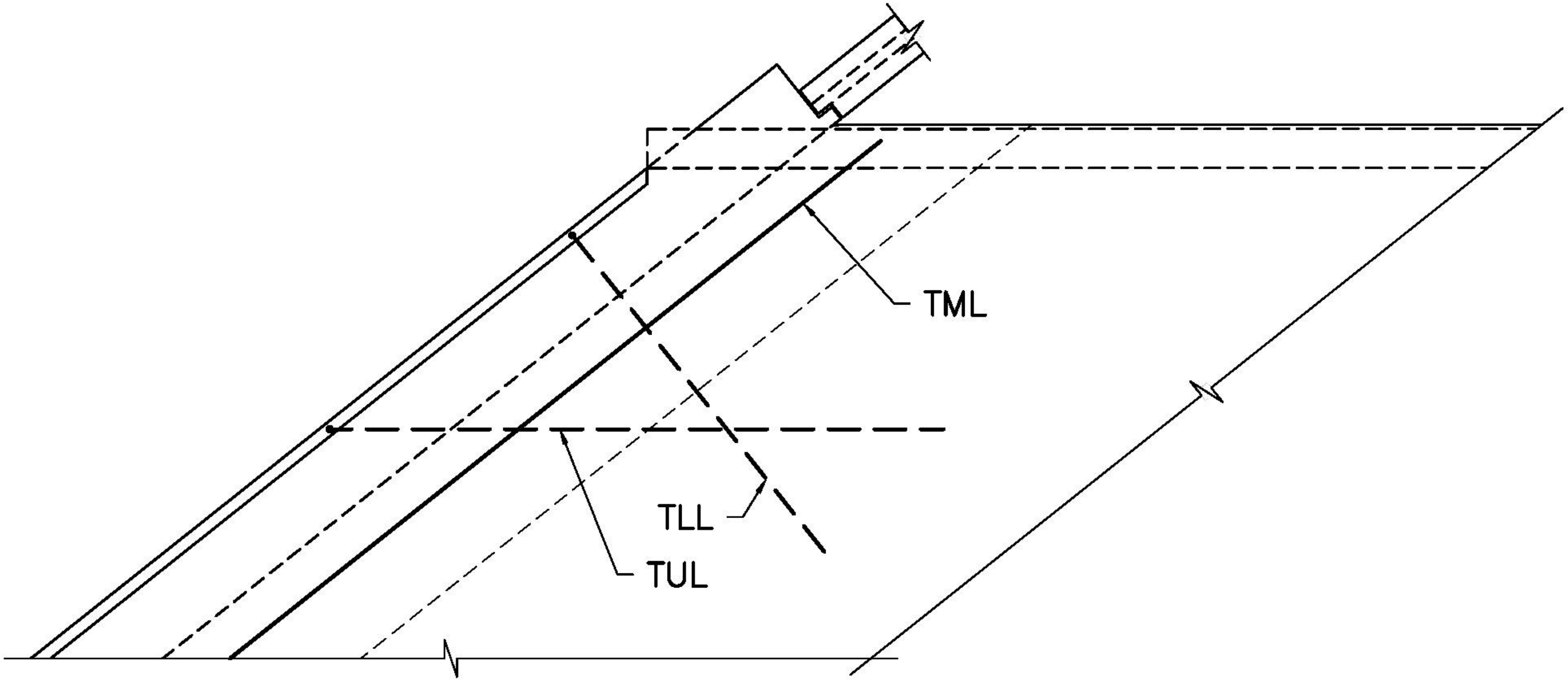
## Structural Capacity




Deck Bending Moment (SLS)

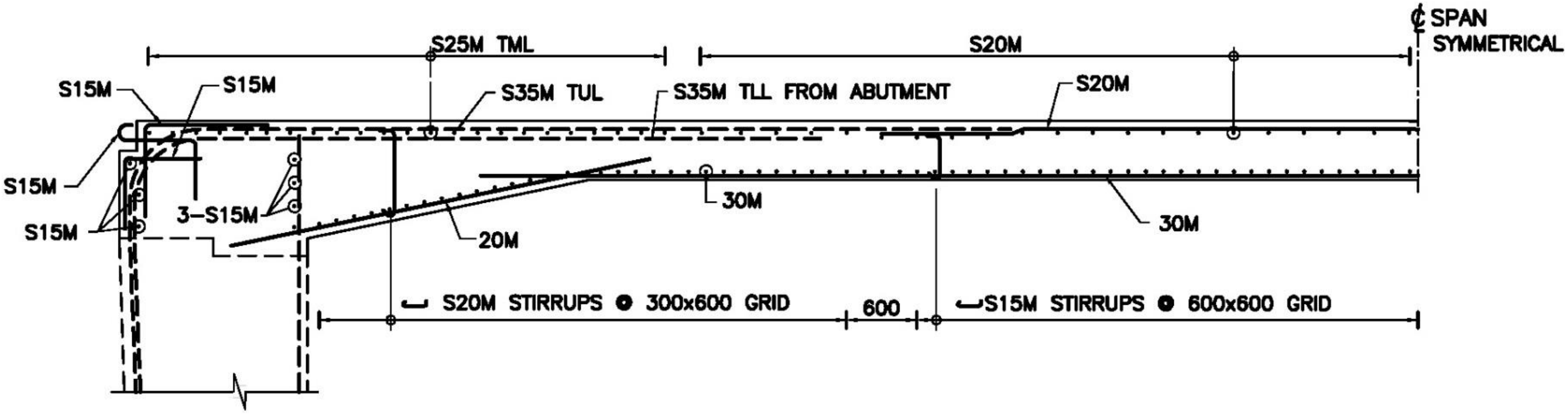
| Moment and Shear (Demand & Capacity) | | Critical Locations | |
|---|---|---|---|
| | | Obtuse Corner (h=1000) | Obtuse Corner (h=750) |
| Moment (kN-m) | Demand | 359 | 252 |
| | Capacity | 416 | 304 |
| | C/D | 1.16 | 1.21 |
| Shear (kN) | Demand | 125 | 80 |
| | Capacity | 1,055 | 817 |
| | C/D | 8.44 | 10.21 |

# WBL DECK REINFORCING




TUL = TOP UPPER LAYER
TML = TOP MIDDLE LAYER
TLL = TOP LOWER LAYER

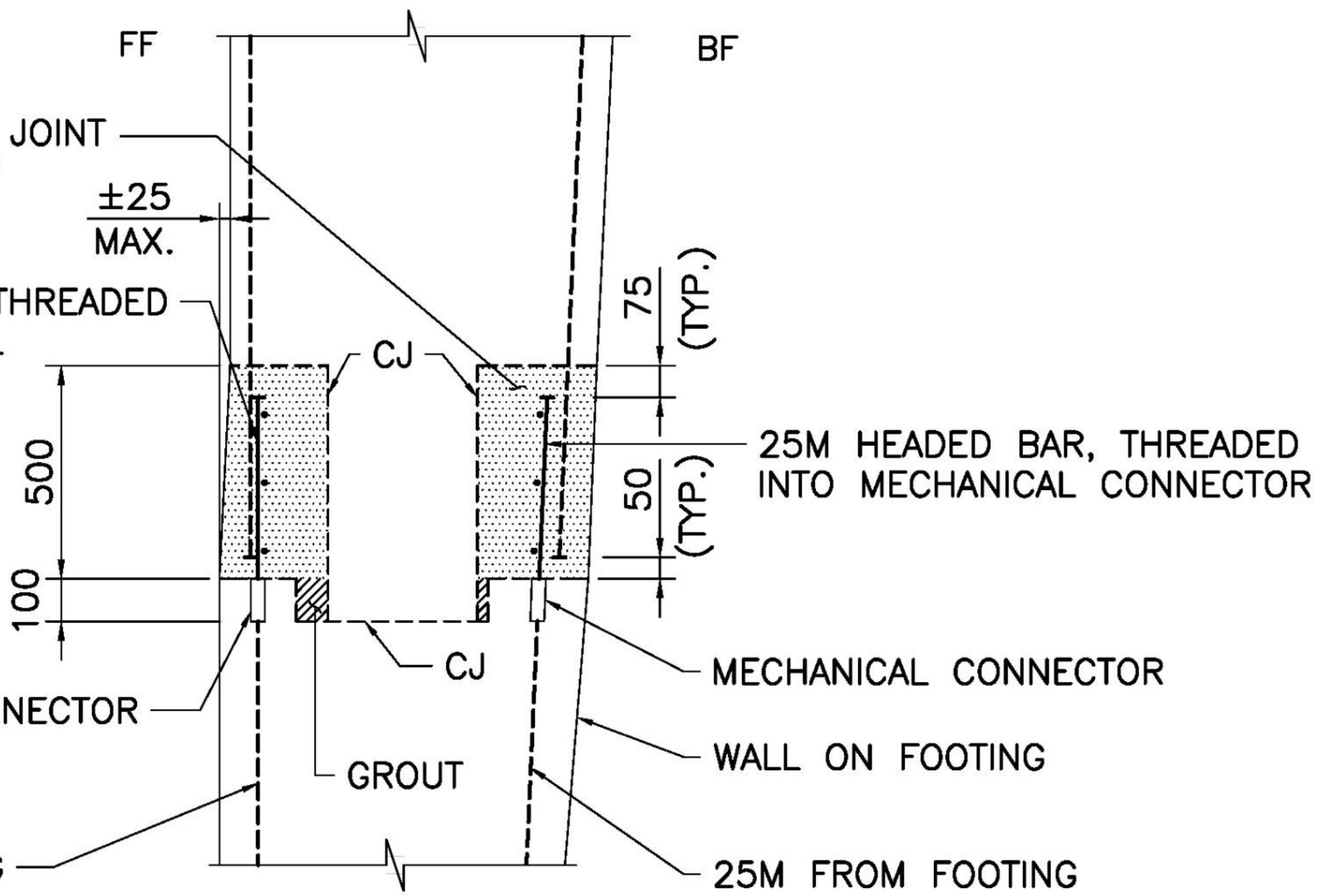
# WBL DECK REINFORCING



# WBL CONSTRUCTION JOINT

- **Bar splice solved with headed bars**
- **Width of key needed to consider:**
  - Theoretical leg deflection
  - Bowing of wall versus footing
  - Tilt of walls
  - Allowable construction tolerances
- **Developed tight construction tolerances to ensure fit**

# WBL CONSTRUCTION JOINT



# WBL CONSTRUCTION TOLERANCES

MMM GROUP

| Dimensions | Tolerance |
|---|---|
| Width of key at top of wall of WBL footing component | +/- 3mm |
| Width of key (stem) at bottom of wall of WBL rigid frame component | +/- 3mm |
| Depth of key at construction joints | +/- 6mm |
| Length of key at bottom of key (wall of rigid frame component) and top of key (wall of footing component) | +/- 13mm |
| Insert or headed bar location along length of wall | +/- 13mm |
| Insert or headed bar location along width of wall | +/- 10mm |
| Distance between walls at key | +/- 6mm |
| Distance between walls at haunch | +/- 13mm |
| Plumb over height of walls of rigid frame component | +/- 6mm |

# WBL CONSTRUCTION TOLERANCES

- **No single tolerance was actually met during construction, but fit like a glove anyway**

## LESSON LEARNED

- The accumulation of maximum tolerances is unlikely (could consider relaxation of concrete dimensional tolerances)
- Bar placement to tight tolerances is achievable in the field (no conflicts with upper and lower headed bars)
- Model agreed closely with observed

# EBL OVERVIEW

- **EAST BOUND LANE – SINGLE PIECE WITH FOOTINGS**
  - Engineering Challenges
  - RBR Configuration for *Single Piece Rigid Frame* Move
  - Equipment
  - Modeling and  Analysis

# EBL - CONCRETE RIGID FRAME ONE PIECE

# EBL - CONCRETE RIGID FRAME ONE PIECE

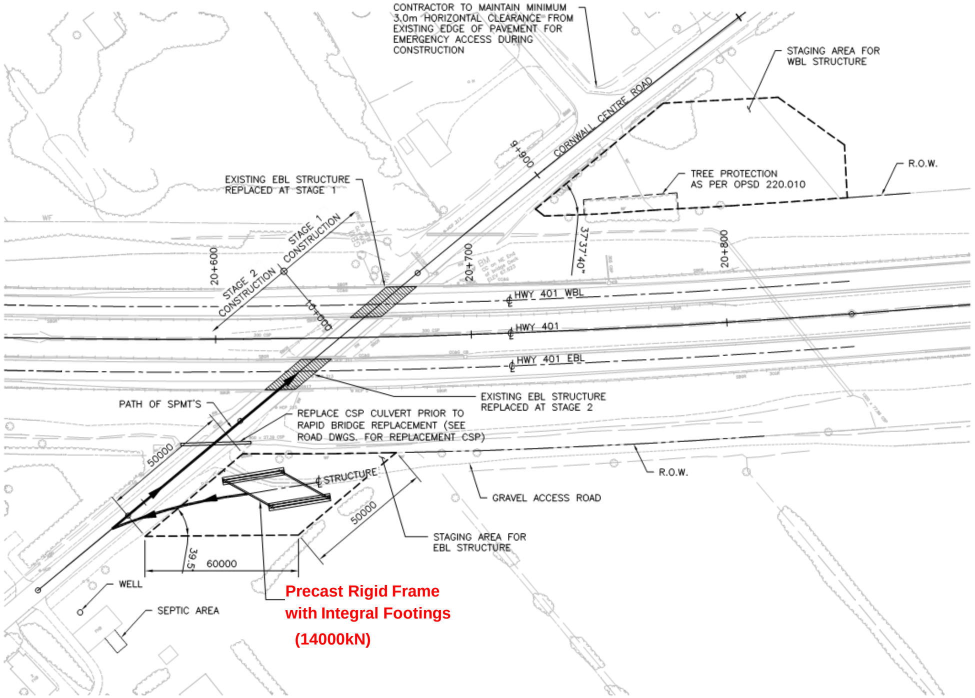
# EBL ENGINEERING CHALLENGES

MMM GROUP

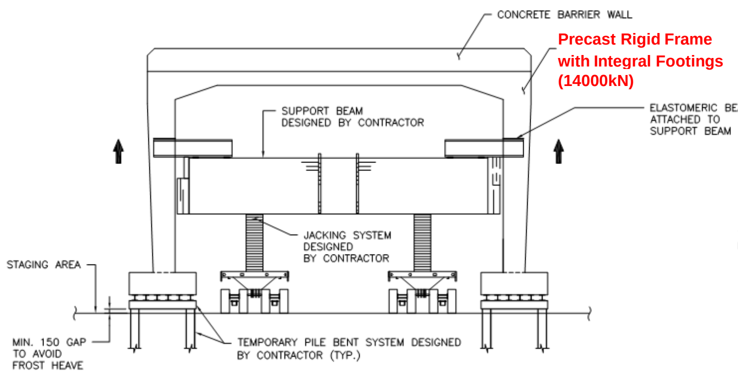
- Heavy Load (1400 tonnes)
- Load concentrated at obtuse corners
- Short structure span limits space for SPMT's
- Required to lower entire structure 1.5 m at destination (beyond jack stroke of SPMT's)
- Depth of lifting beam and SPMT equipment restricts space available of climbing jacks
- Structure deflects/twists when lifted

# EBL – OVERVIEW

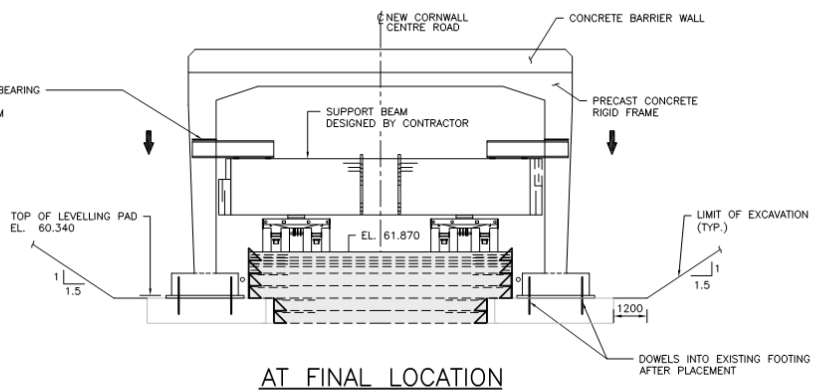
MMM GROUP




PLAN
1:1000



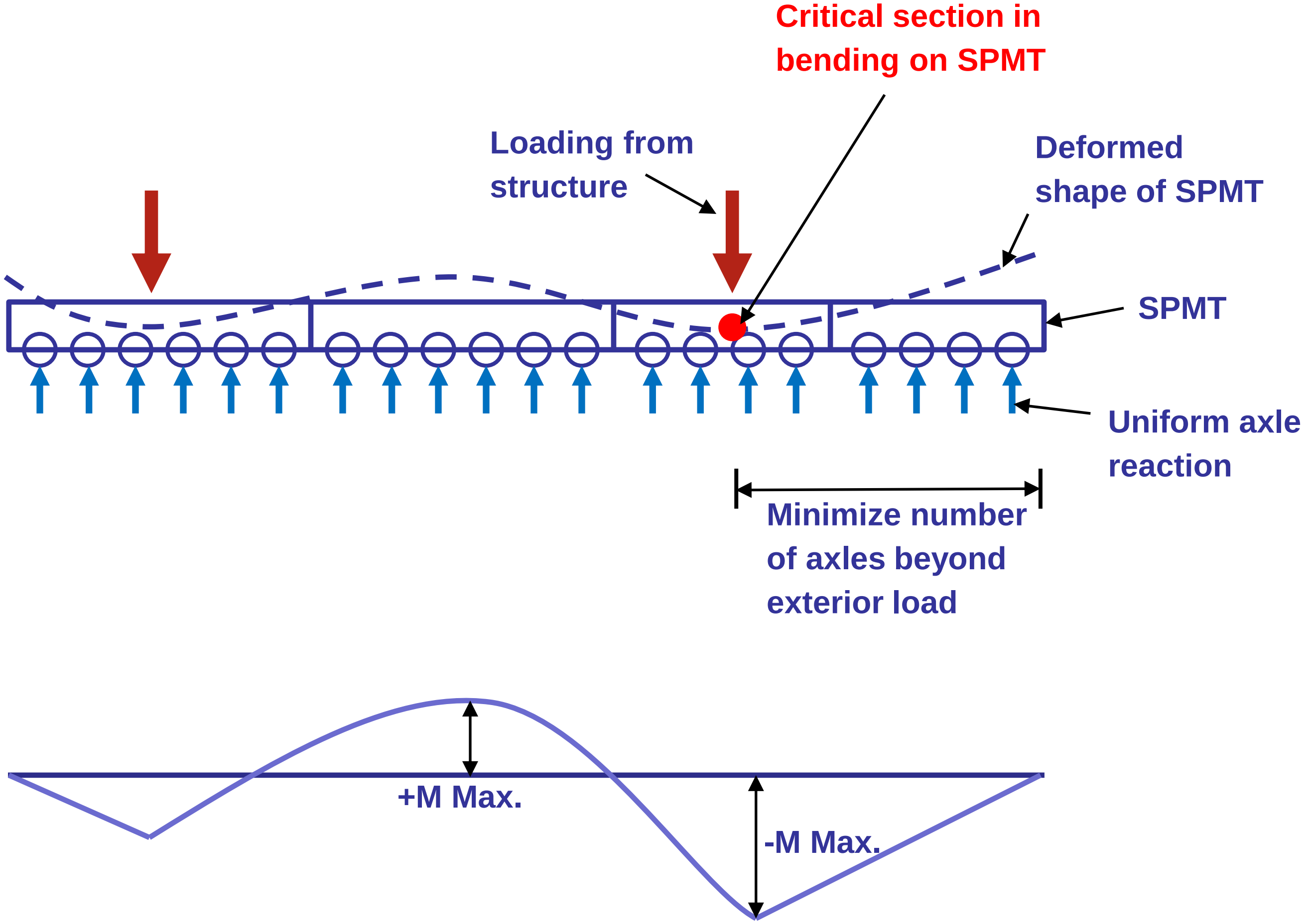

AT STAGING AREA
N.T.S.



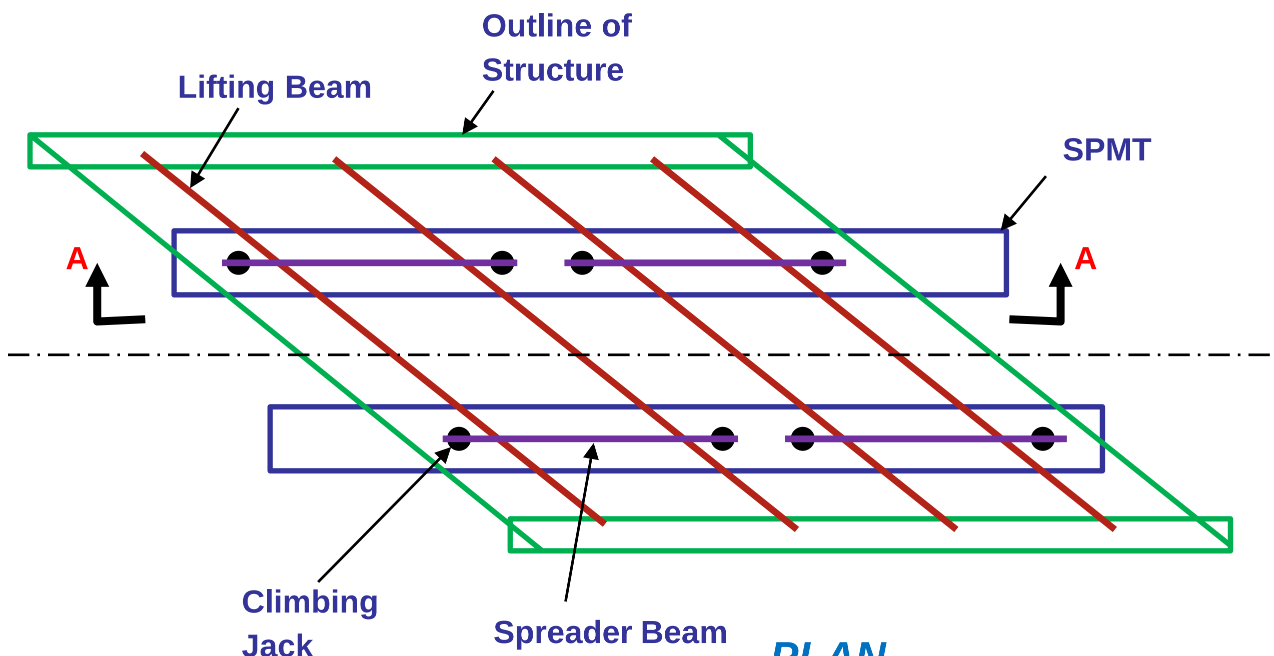

AT FINAL LOCATION
N.T.S.

# EBL – LIFTING SYSTEM

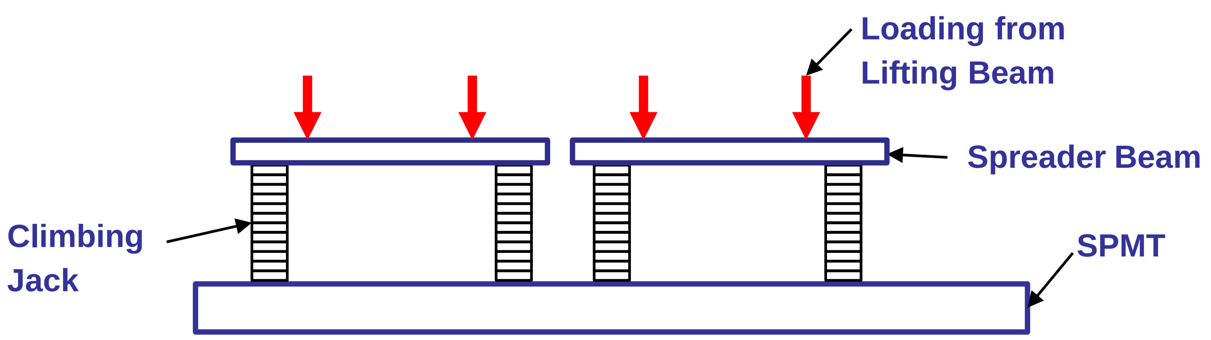
## SPMT Configuration



# EBL – LIFTING SYSTEM




***PLAN***




***Section A-A***

# EBL – EQUIPMENT

MMM GROUP

## SPMT – Kamag 2400ST

Technical data

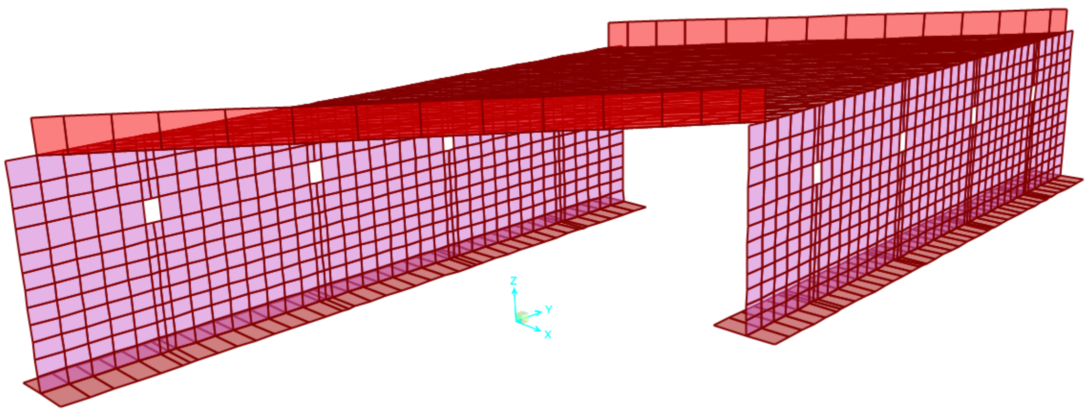
| Item | 51000165 | | 51000164 | |
|---|---|---|---|---|
| Type | K 2406 ST HS4E | | K 2406 HS4E | |
| Tyre filling | PU-filling | | Air-filling 10 bar | |
| Speed | 1 km/h | 3 km/h | 1 km/h | 3 km/h |
| Payload | 261,000 kg | 213,000 kg | 202,800 kg | 186,000 kg |
| Admissible gross weight | 288,000 kg | 240,000 kg | 228,000 kg | 211,200 kg |
| Dead weight | 27,000 kg | | 25,200 kg | |
| Admissible axle load | 48,000 kg | 40,000 kg | 38,000 kg *) | 35,200 kg |
| Platform dimensions | approx. 8,400 x 2,430 mm | | | |
| Coupling lentgh | approx. 8,400 mm | | | |
| Platform height driving position | approx. 1,490 mm | | | |
| Axle compensation | approx. +/- 350 mm | | | |
| Platform height lowered | approx. 1,140 mm | | | |
| Steering / steering angle | elektronical-hydraulical approx. + 130°/-100° | | | |
| Number of wheel bogies / braked | 12 / 6 | | | |
| Wheel bogies driven | 4 | | | |
| Tractive force | 240 kN | | | |
| Brake performance | 240 kN | | | |

*) max distance less than 300m, at 0.5 km/h and distance less than 300m: 40,000 kg

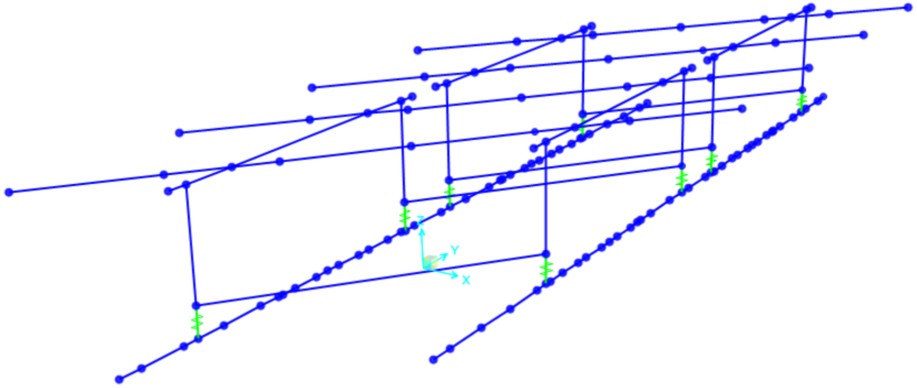
## Climbing Jack – CS250

# EBL – MODELING & ANALYSIS

## Structural Modeling



Concrete Rigid Frame Modeling – Shell Element



Transport System Modeling – Beam Element

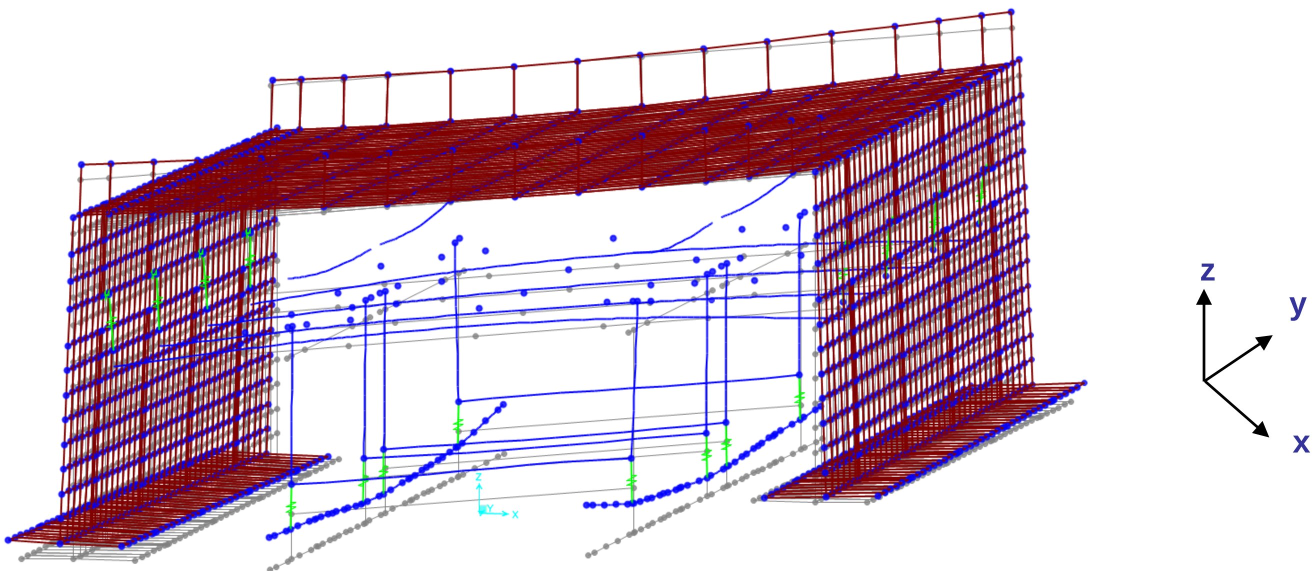
# EBL – Results

## Reactions at Block-outs

| Location | Reactions | |
|---|---|---|
| | Flexible | Infinite Stiffness |
| Block-out 1 (Obtuse corner) | 2403 kN | 2200 kN |
| Block-out 2 | 1272 kN | 1800 kN |
| Block-out 3 | 1174 kN | 1600 kN |
| Block-out 4 (Acute corner) | 2114 kN | 1400 kN |

# EBL – Results

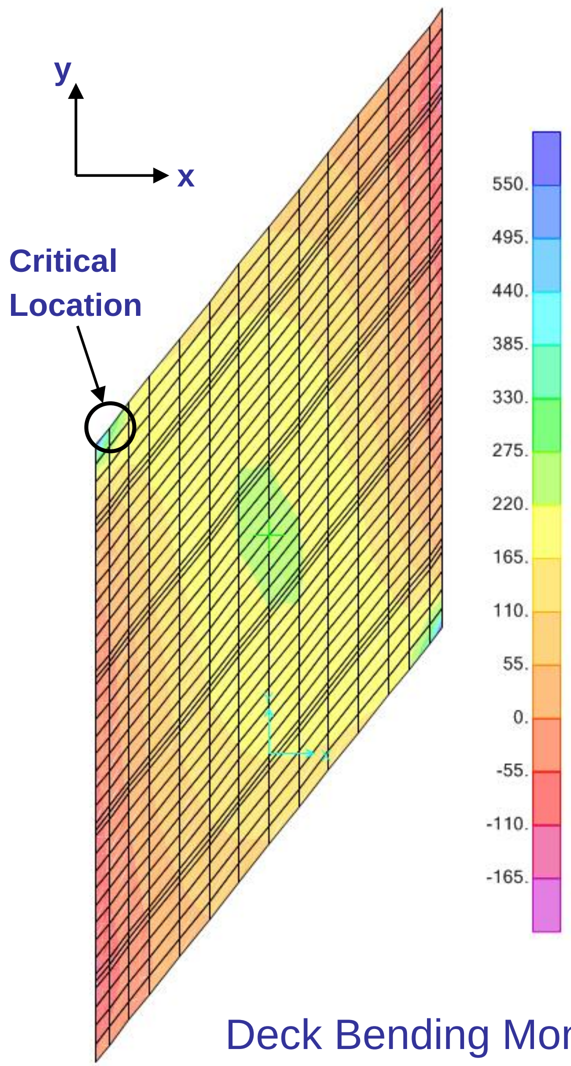
## Deformations




| Location | Displacements (mm) | | |
|---|---|---|---|
| | x (perpendicular to centreline of CCR) | y (parallel to centreline of CCR) | z (vertical direction) |
| Deck – Centre (Base Point) | 0 | 0 | 0 |
| Deck – Obtuse Corner | 0 | 0 | 10.6 |
| Deck – Acute Corner | 1.1 | -0.1 | 32.7 |
| Wall Base – Obtuse Corner | 22.1 | 6.5 | 9.9 |
| Wall Base – Acute Corner | 27.0 | 6.5 | 33.5 |

# EBL – Results

## Structural Capacity




Deck Bending Moment (SLS)

| Moment and Shear (Demand & Capacity) | | Critical Locations | |
|---|---|---|---|
| | | Obtuse Corner (h=1000) | Obtuse Corner (h=750) |
| Moment (kN-m) | Demand | 381 | 256 |
| | Capacity | 416 | 304 |
| | C/D | 1.09 | 1.19 |
| Shear (kN) | Demand | 120 | 83 |
| | Capacity | 1,055 | 817 |
| | C/D | 8.79 | 9.84 |

# EBL - CONCRETE RIGID FRAME ONE PIECE

# EBL - CLIMBING JACK

# EBL - FINAL DESTINATION

# EBL - RESTRAINT SYSTEM

# EBL - MOVE

# EBL MOVE

# EBL MOVE

MMM GROUP

# EBL MOVE

MMM GROUP

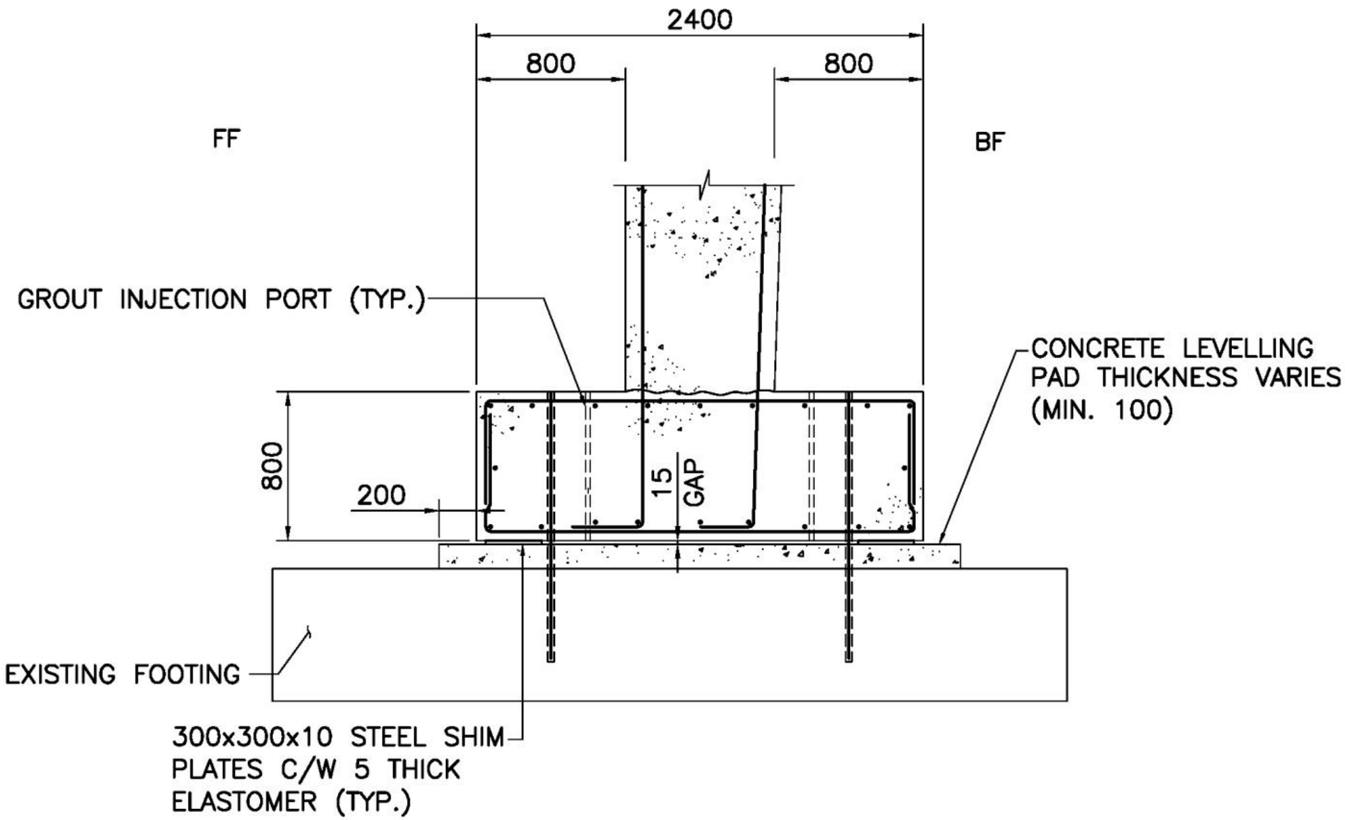
# EBL MOVE

# EBL MOVE

# EBL MOVE

MMM GROUP

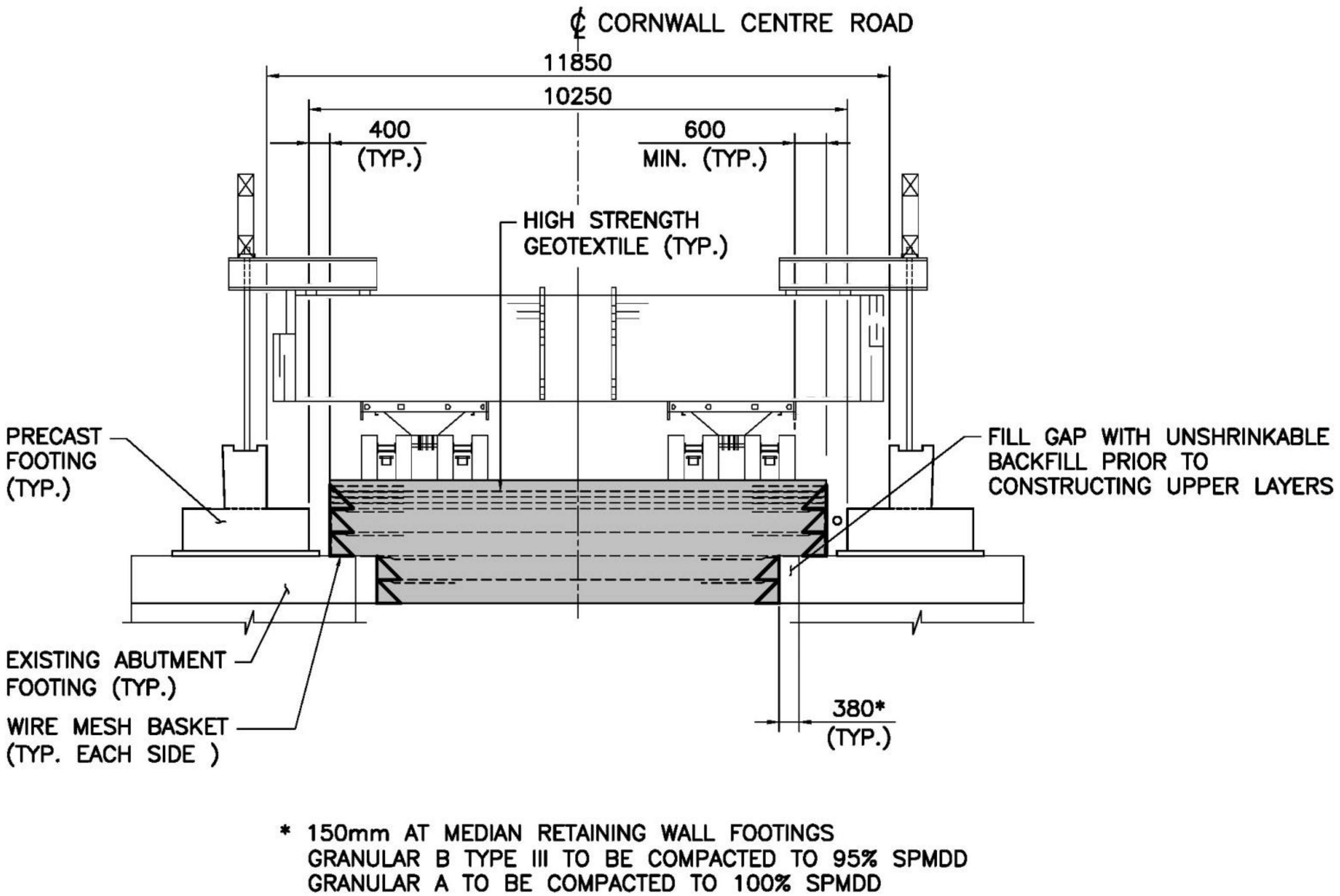
# EBL FOOTING DETAIL



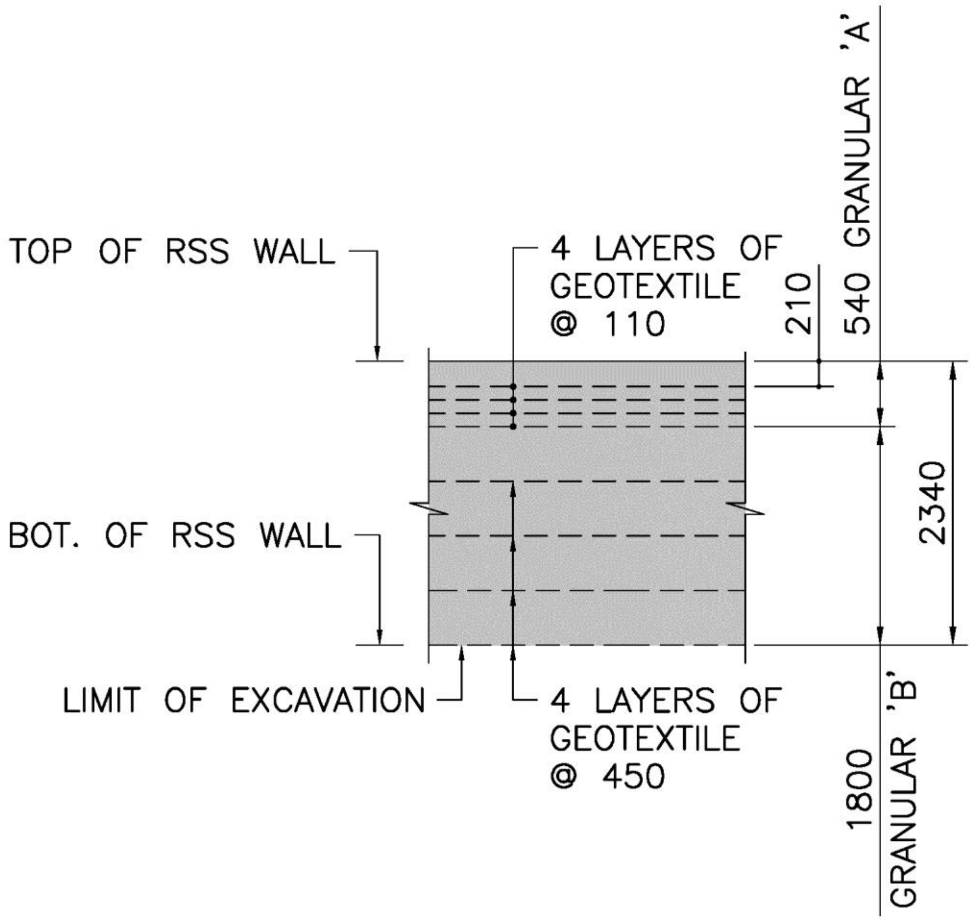
# PRESENTATION OVERVIEW

- **LESSONS LEARNED**
  - Temporary RSS Wall
  - Pressure Grouting
  - Steel Forms
  - Bearings at Lifting Points
  - Skews/Twist
  - Tie Bars

# TEMPORARY RSS WALL



# TEMPORARY RSS WALL



# TEMPORARY RSS WALLS

MMM GROUP


Climbing jacks hydraulic pump failure caused RSS wall to sustain load for 24 hrs

Proved capable of withstanding heavy loads close to vertical edge

# LESSONS LEARNED

- **PRESSURE GROUTING**
  - Experienced contractor (skipped every other grout holes creating air pockets)
  - Sufficient equipment (tried to use one grout pump for both sides of wall)
  - Was grout strength attained before WBL rigid frame lift? (only needed low strength $< 1$ MPa)
  - Cores for dowels detected voids
  - Ensure test cores are done before backfilling AND BEFORE SETTING RIGID FRAME TOP PIECE ON IT!

# LESSONS LEARNED

- **STEEL FORMS**
  - Unyielding form at bearing of rigid frame legs unable to accommodate rotation when deck falsework removed
  - Concrete cover on sides of male key spalled off

# LESSONS LEARNED

MMM GROUP

- **STEEL FORMS**
  - Unyielding form at bearing of rigid frame legs unable to accommodate rotation when deck falsework removed
  - Concrete cover on inside of male keys spalled off

# LESSONS LEARNED

## ▸ BEARINGS AT LIFTING POINTS

- ▸ Elastomeric bearing pads on top of steel beams shown on drawings, but were not installed at time of move
- ▸ Concrete cover on sides of pocket spalled off

# LESSON LEARNED

- **BEARINGS AT LIFTING POINTS ARE NOT OPTIONAL**

# LESSONS LEARNED

- **SKEWS AND TWIST**
  - Analysis assumed infinite stiffness are lifting points (inserted pin-roller in finite element model)
  - Actual SPMT system and lifting beams are flexible
  - Review with specialists during design did not address lifting system flexibility and impact on structure
  - Consider CMGC procurement to have Engineer and Contractor work together (to devise system to suit Contractors equipment and beam stockpile)
  - Consider maximum 20° skew to provide more uniform loading
  - Have lifting analysis done before casting concrete (could have added more reinforcing to soffit to accommodate twist)

# LESSONS LEARNED

- **TIE BARS**
  - Did not work as intended (sag in some bars remained after lifting while others straightened out)
  - Practically impossible to align holes from one wall to the other wall.  Binding in holes caused “S” shape deflection in bars
  - Recommend pretensioning of bars be based on jack pressures instead of sag measurements (“S” shape was horizontal)
  - Provide hinge connection in bars at interior faces of walls to address alignment problems
  - Proved not needed with alternative configuration of SPMT’s

# LESSONS LEARNED

- **WBL - TIME TO CONSTRUCT**
  - 39 days total
    - 6 days shift traffic and demolition
    - 6 days low performance RSS wall
    - 13 days high performance RSS Walls and backfilling
- **EBL – TIME TO CONSTRUCT**
  - 34 days total
    - 5 days less than WBL due to omission of construction joint
- **PRECASTING AND PREPARATION OF MEDIAN CROSS-OVER**
  - 80 days total

# ACKNOWLEDGEMENTS

MMM GROUP


- AECON – General Contractor
- MAMMOET – Subcontractor For Heavy Lift Move
- SARENS – Heavy Lift Specialist (Constructability Review)
- ALTON ASSOCIATES – Temporary RSS Wall Design
- MORRISON HERSHFIELD – Contract Administrator (Construction Photographs)
- Han Choi, Ph.D, P.Eng – MMM Design Engineer
- Ying Yang, P.Eng – MMM Checking Engineer
- MTO – Angela Stewart, Project Manager (Design)
- MTO – Mike DeLugt, Project Manager (Construction)

# Questions?