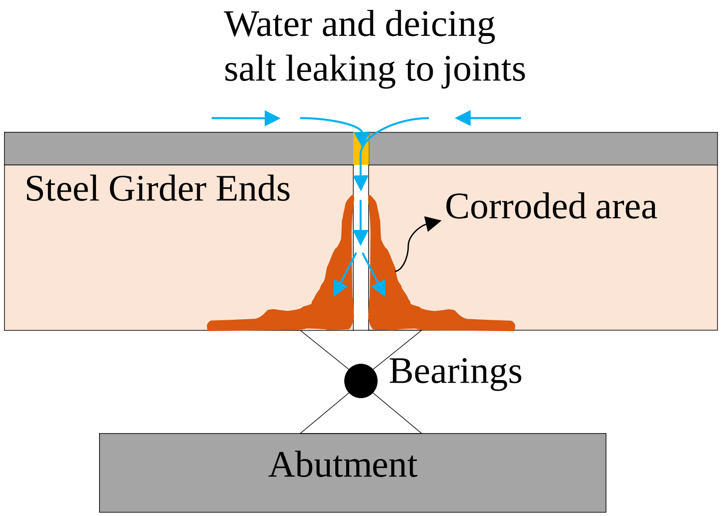
Investigating the shear buckling and ultimate shear strength of girder end web plate based on corrosion damage pattern

University of the Ryukyus

1. Introduction



Severe Corrosion Pattern

1.2. Problem Statement

a) Investigating the corrosion patterns and their effect over shear capacity of steel girders.

b) Evaluating and identifying the severity of the damage patterns in girder ends.

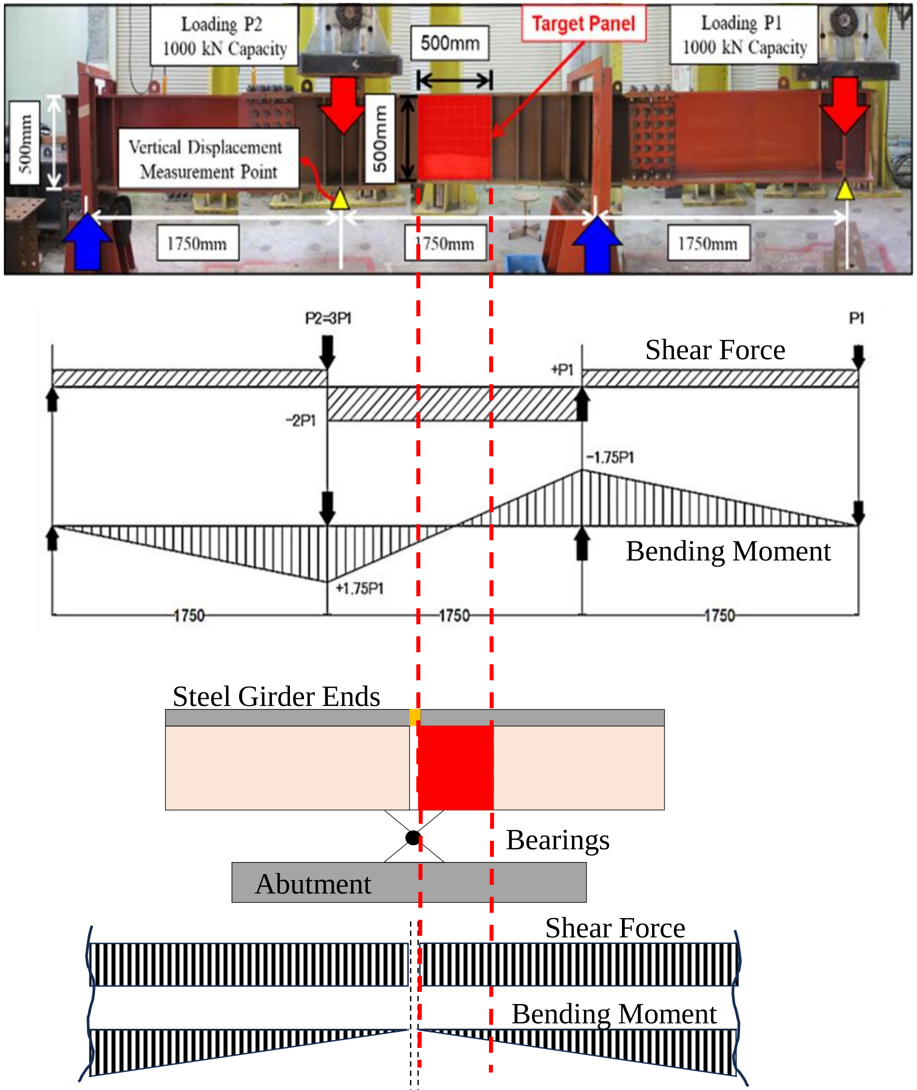
1.3. Purpose

a) This study aimed to evaluate the shear capacity reduction by each corrosion pattern

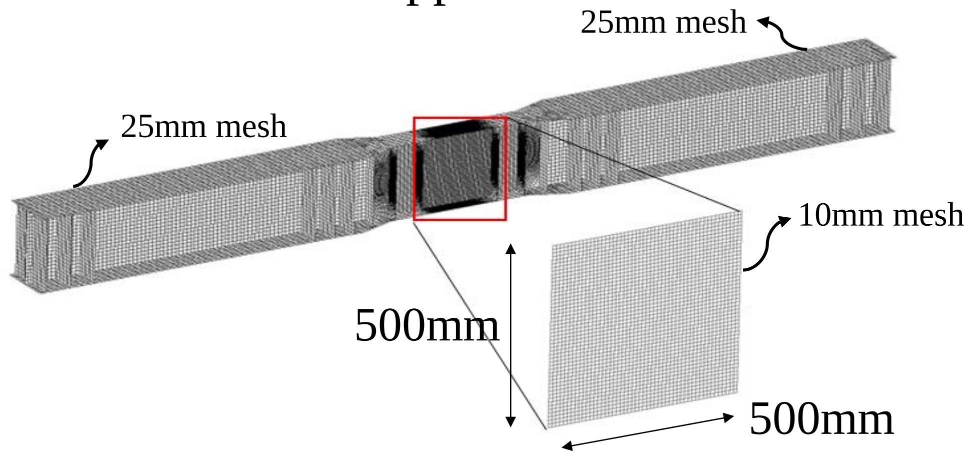
b) Identifying the most severe case and pattern of corrosion affecting the shear strength of the steel girder.

2.1. Methods and Material

2.1.a. Experimental Approach



2.1.b. Numerical Approach



Utilized software: Abaqus 2022

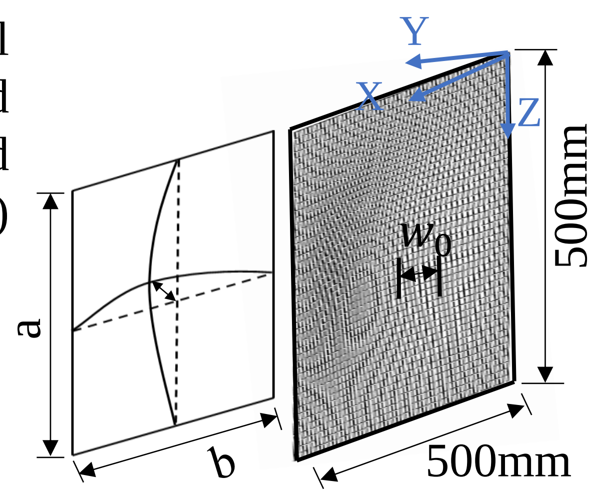
Element Type: Shell element (type S4R)

Mesh size: Focus panel (10mm), model (25mm)

Maximum initial deflection allowed per Japan Road Association (JRA) is b/150.

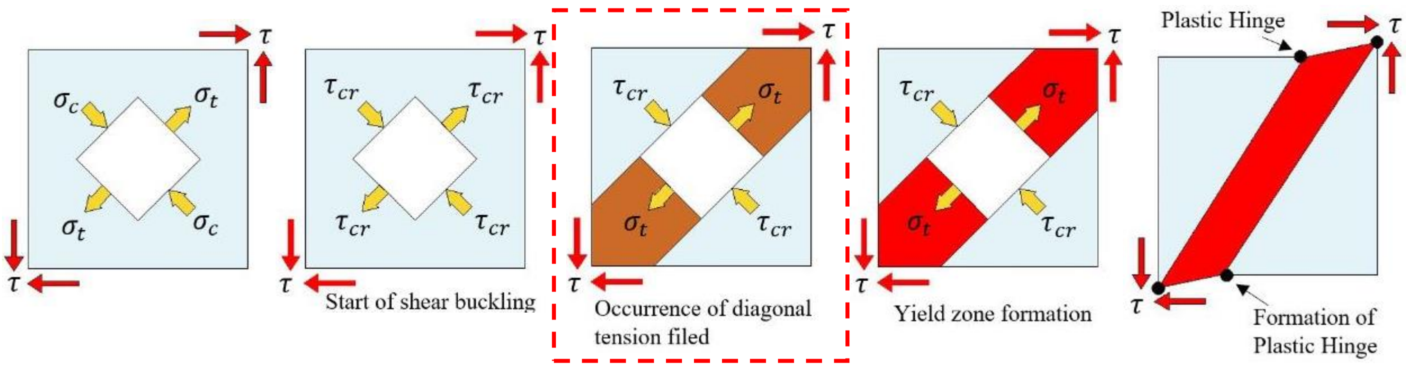
Max Def b/150 = 3.3mm

- Def. mode 1

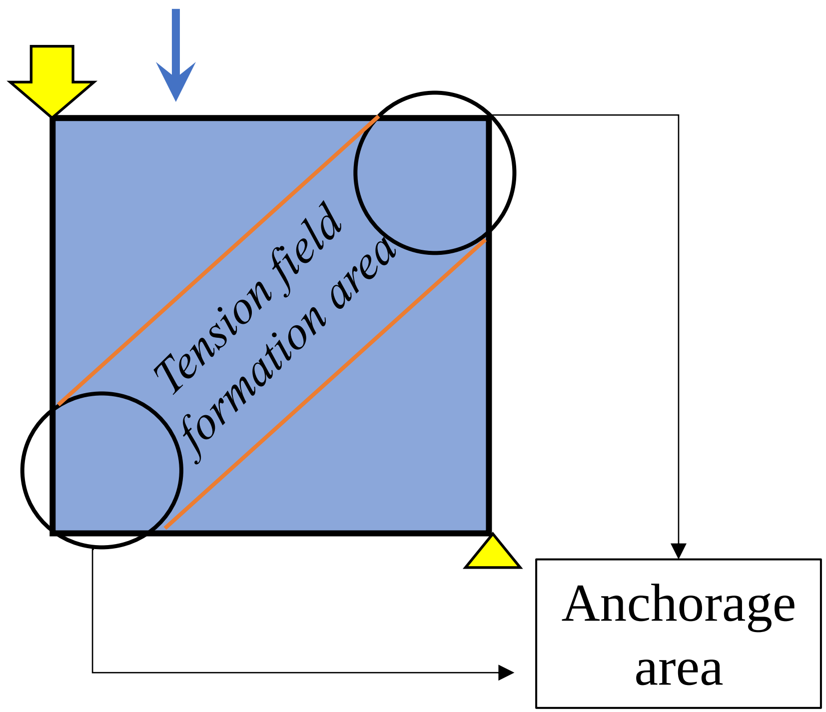


2.2. Methods and Material

2.2. Shear stress distribution and Anchorage Role

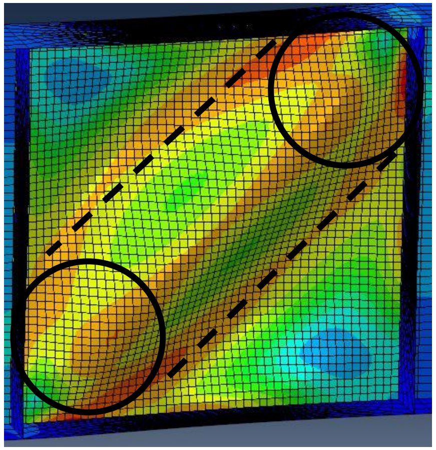


Tensile field forms within anchorage area, corrosion in this area affects Yield zone and plastic hinge affecting total shear strength.



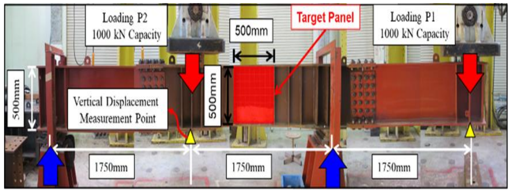
Base case Experimental model tensile field

Base case Numerical model tensile field

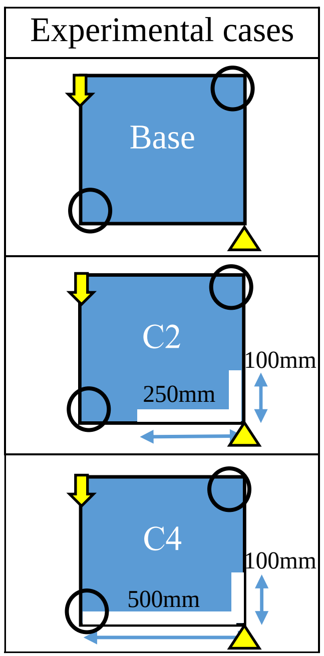


3. Severe Corrosion Parameters

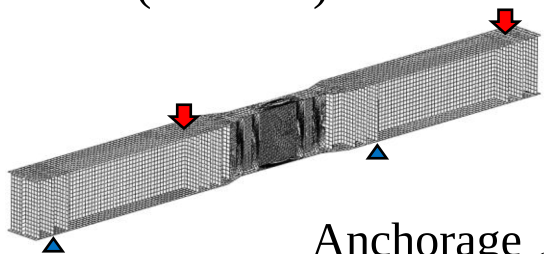
Experimental Parameters (3 cases)

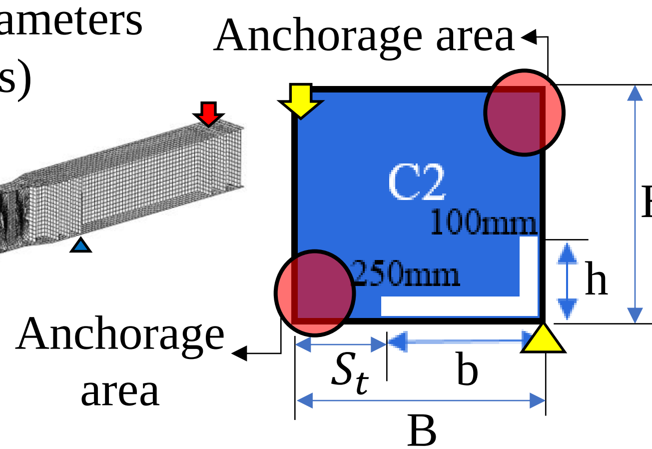


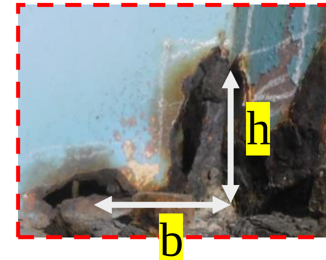
Base C2 C4



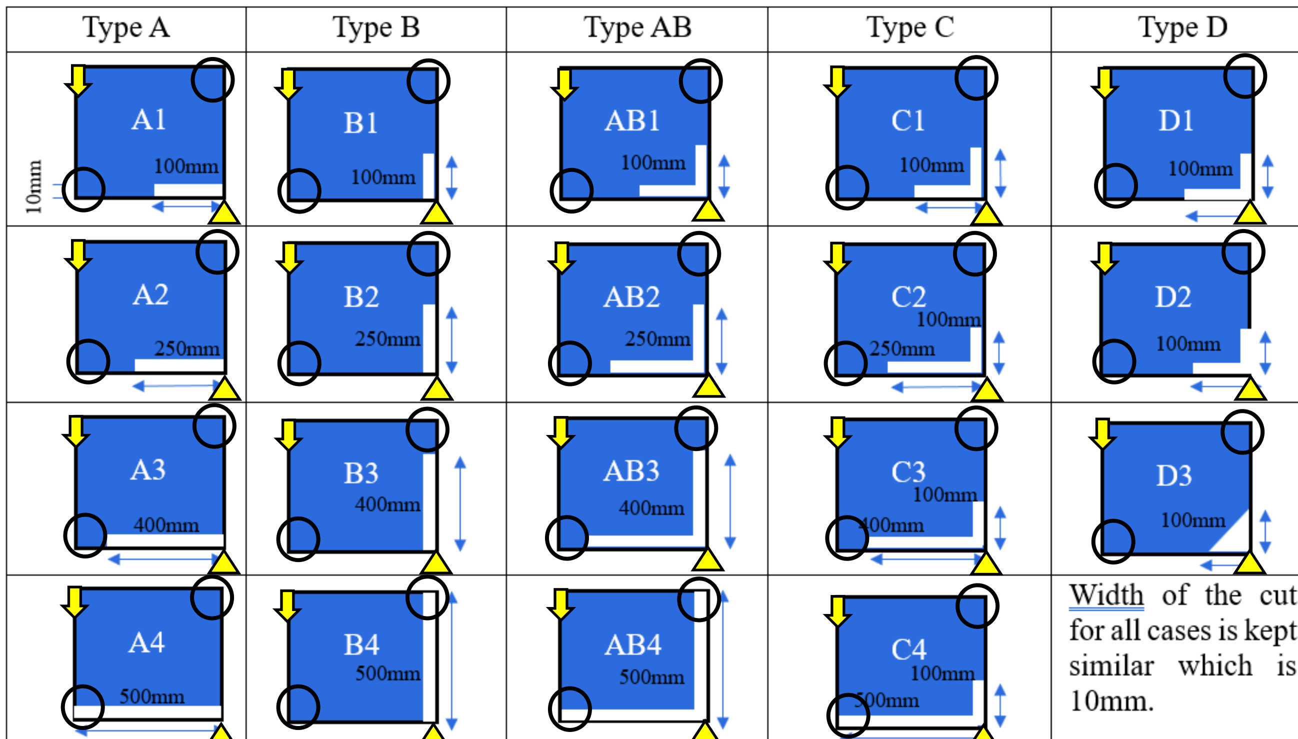
Numerical Parameters (19 cases)





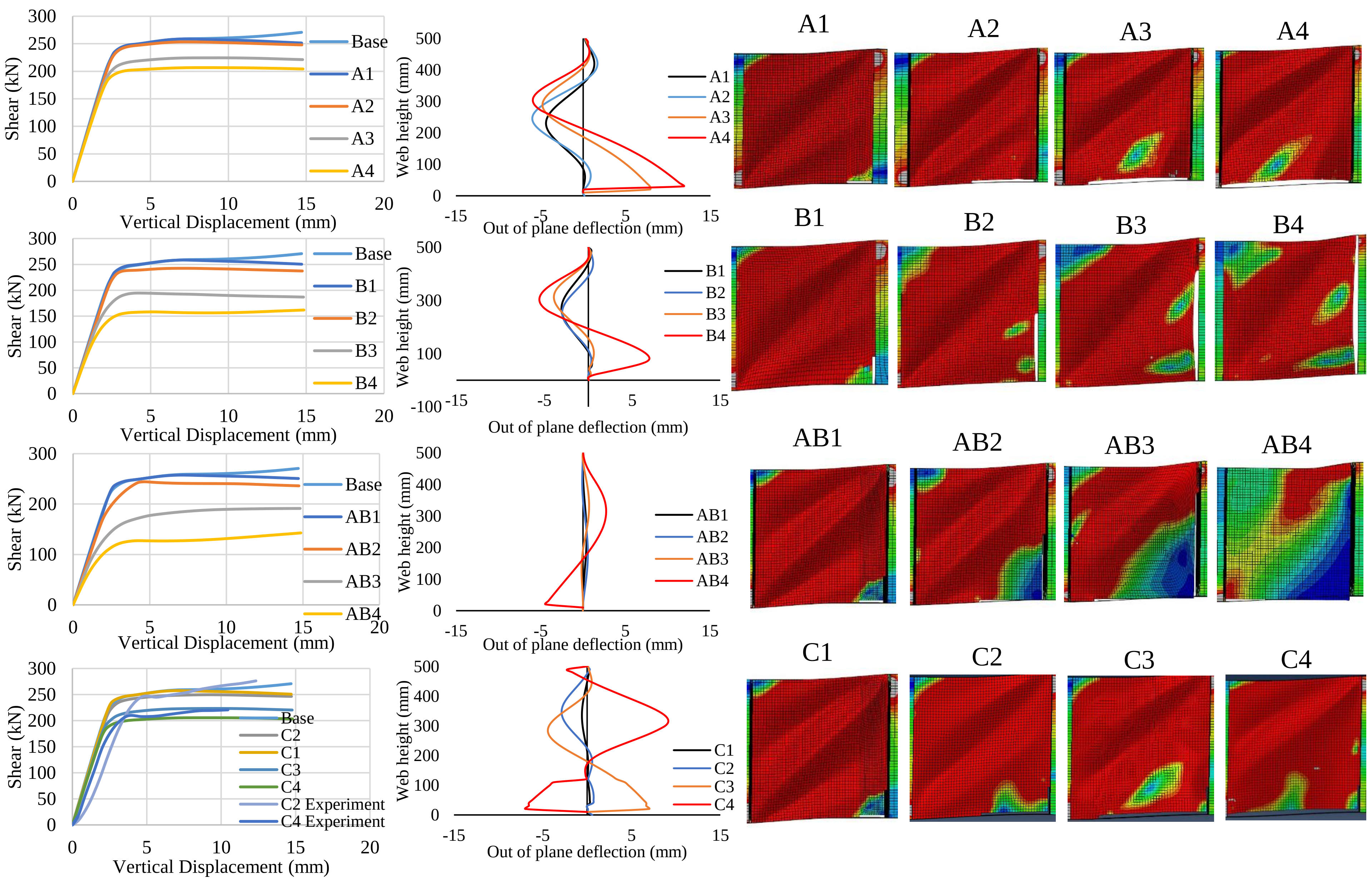


H = web Height (500mm)
h = Corrosion height
B = Web width (500mm)
b = Corrosion width



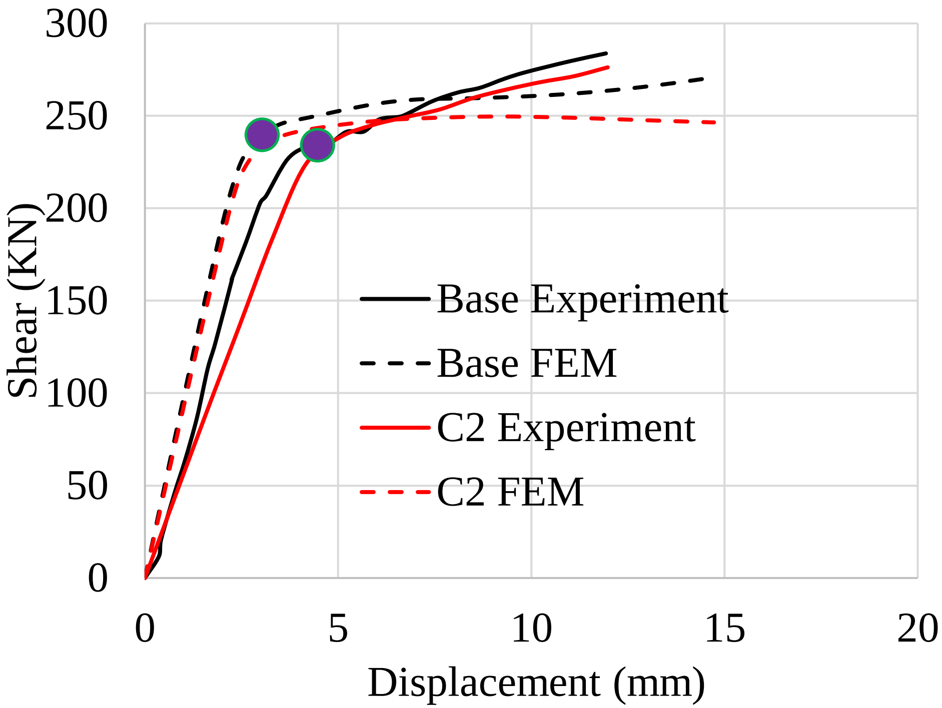
Width of the cut for all cases is kept similar which is 10mm.

4.1. Results

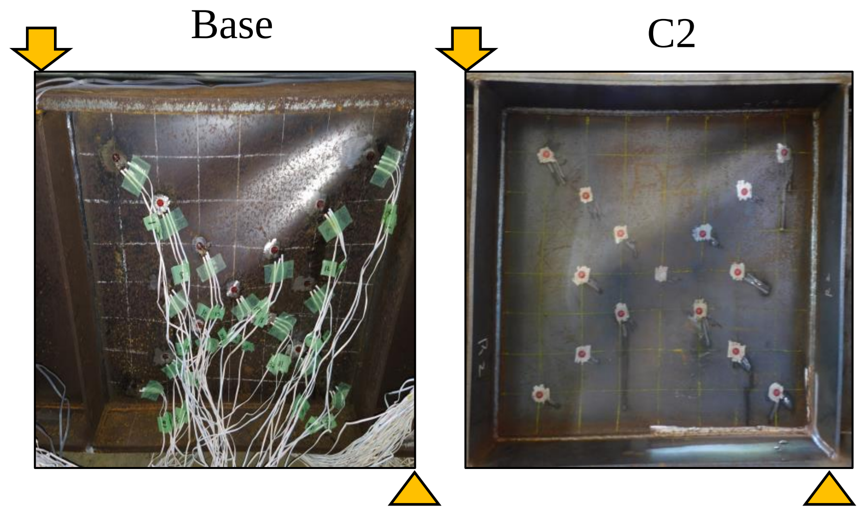


Shear (kN)
Vertical Displacement (mm)
Base
A1
A2
A3
A4
Web height (mm)
Out of plane deflection (mm)
B1
B2
B3
B4
AB1
AB2
AB3
AB4
C1
C2
C3
C4
C2 Experiment
C4 Experiment

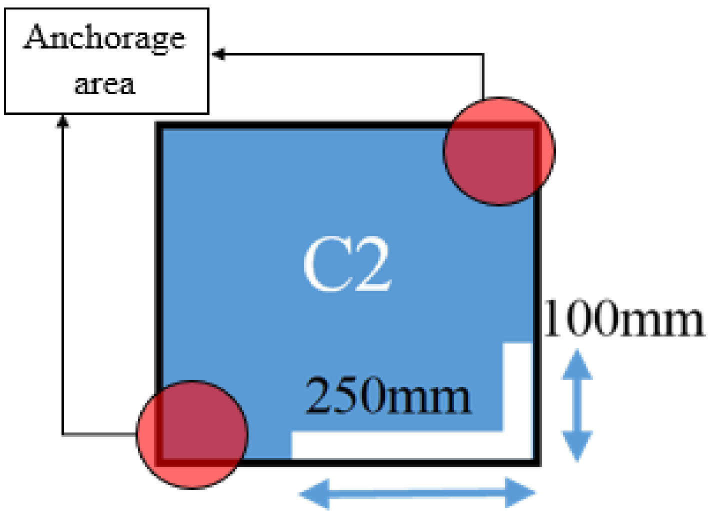
4.2. Results



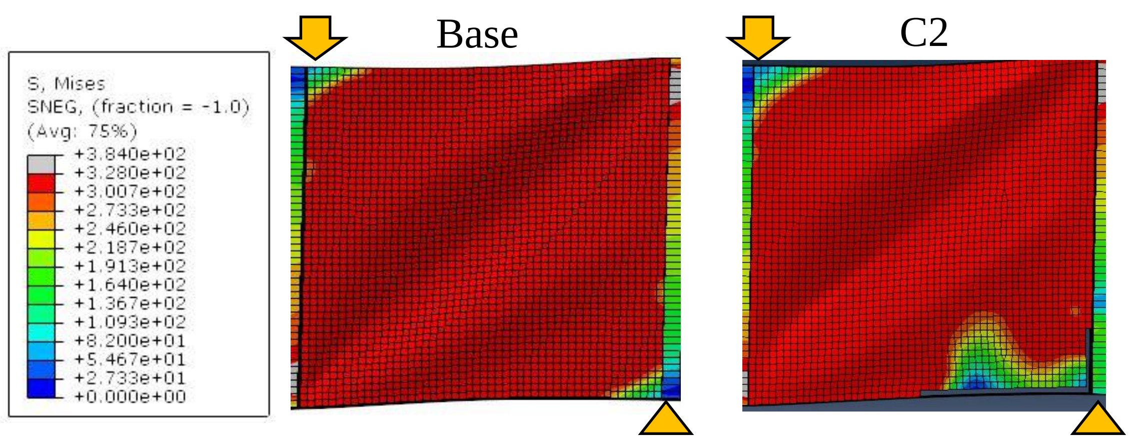
Shear (KN)
300
250
200
150
100
50
0
0
5
10
15
20
Displacement (mm)
Base Experiment
Base FEM
C2 Experiment
C2 FEM



Base
C2

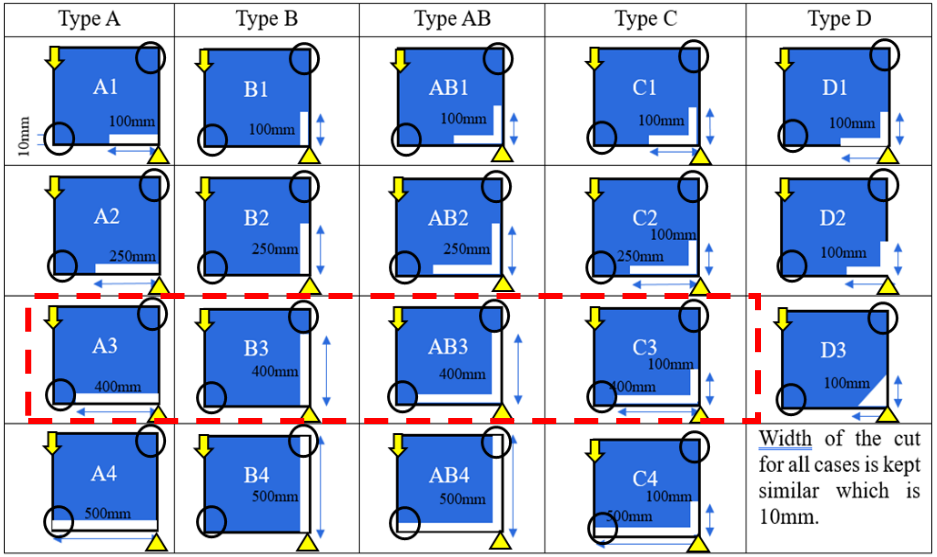


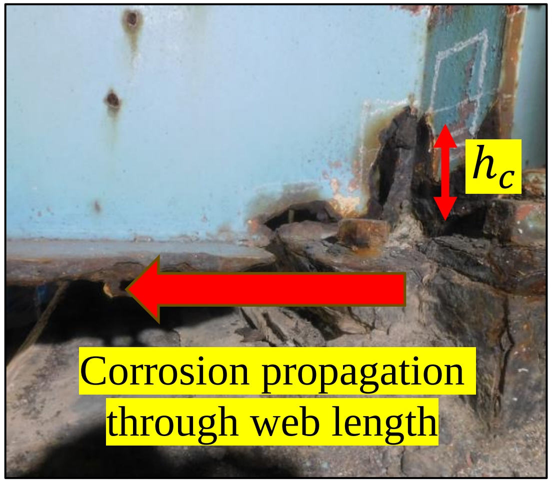
Anchorage area
C2
100mm
250mm



S, Mises
SNEG, (fraction = -1.0)
(Avg: 75%)
+3.840e+02
+3.280e+02
+3.007e+02
+2.733e+02
+2.460e+02
+2.187e+02
+1.913e+02
+1.640e+02
+1.367e+02
+1.093e+02
+8.200e+01
+5.467e+01
+2.733e+01
+0.000e+00
Base
C2

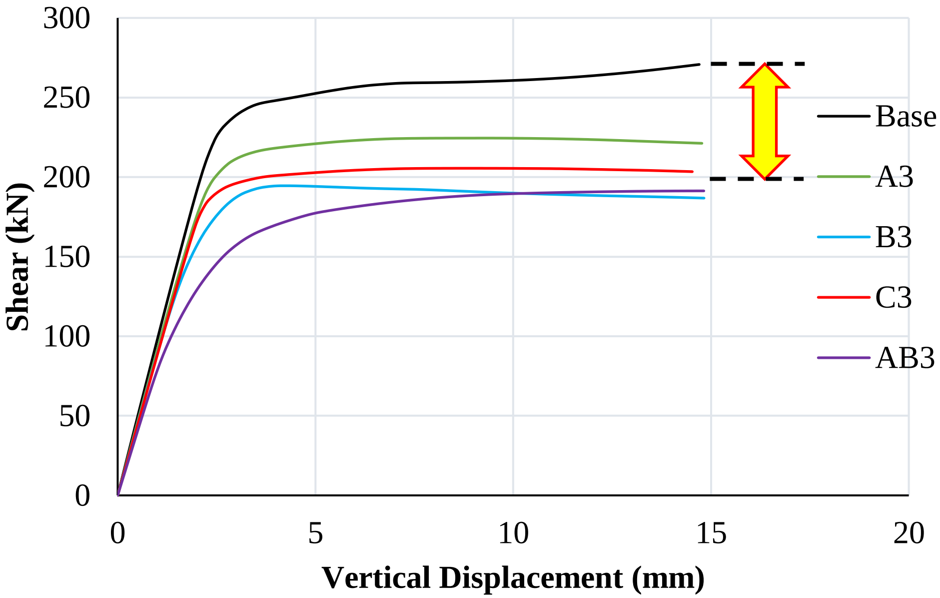
4.3. Results



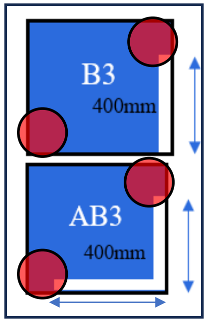


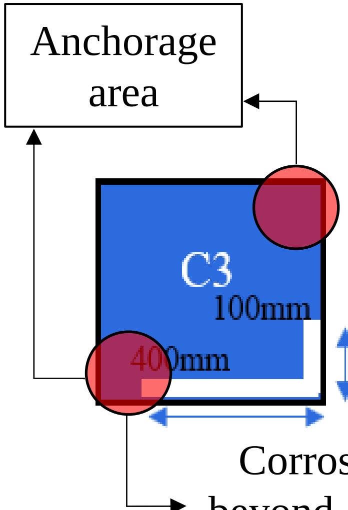
h_c = 100mm

Commonly even in most severe cases the heigh of corrosion is almost around 100mm



First Most severe but NOT IDEAL cases





Second Most severe and IDEAL case

Corrosion affecting beyond anchorage area

5. Conclusions

A. The absence of tension field anchorage significantly reduces the shear strength of the web plate.
B. Numerical analysis confirms that the lack of a vertical stiffener decreases compressive strength due to buckling and the weaker column effect, impacting shear buckling.
C. Corrosion patterns like AB4, with severe corrosion in both tension field anchorage areas, result in the absence of a tension field and limited deformation, impacting surrounding stiffeners and flanges. However, such severe corrosion is unlikely in real bridges.

When both anchors are exposed, the shear is drastically decreased, which is not very ideal case to happen. However, corrosion can expand horizontally. So what corrosion case C3 is more ideal and severe

A Study on Efficient Repair Method of Corroded Steel Plate Girder End Using CFRP

1. Introduction

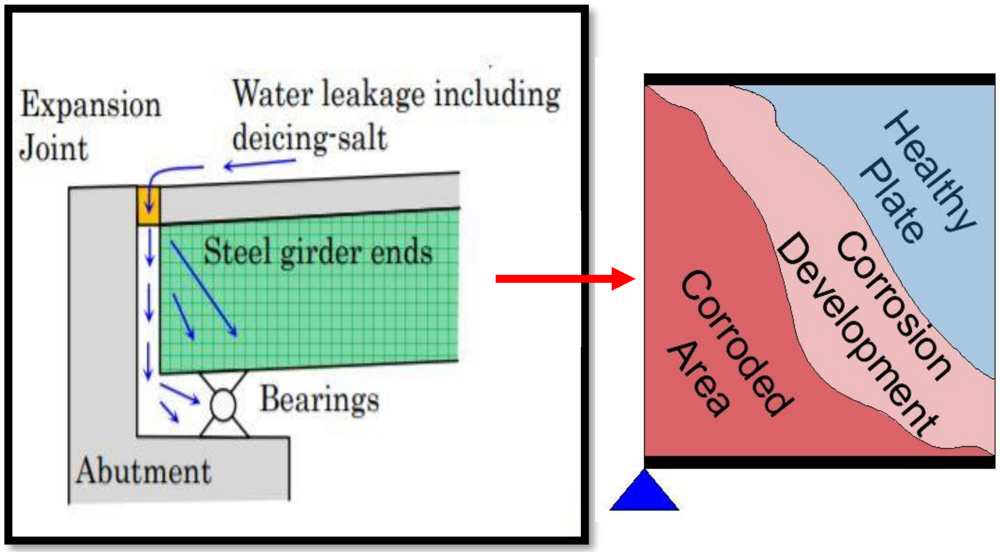
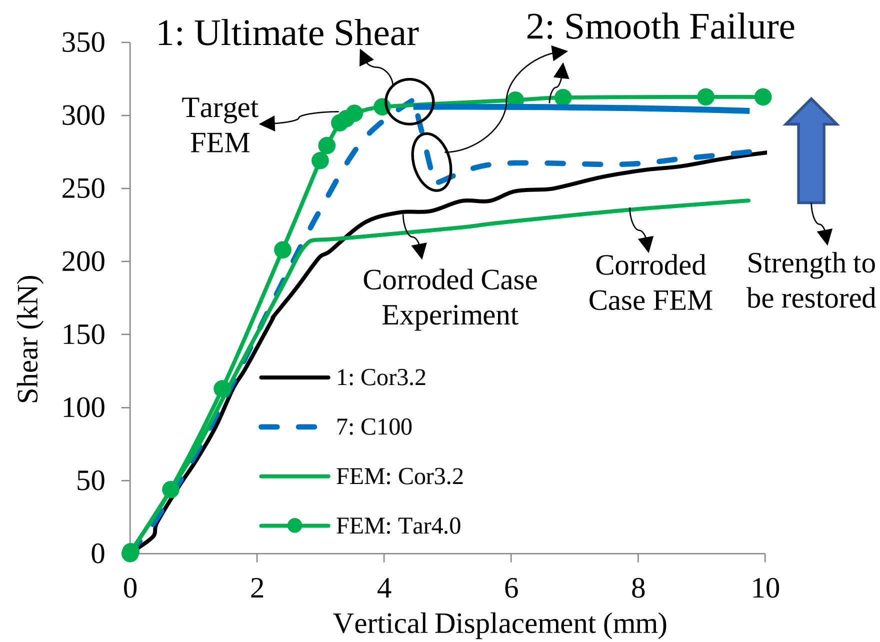


Figure.1 Corrosion formation and Propagation



Study Purpose

1.1. Problem:

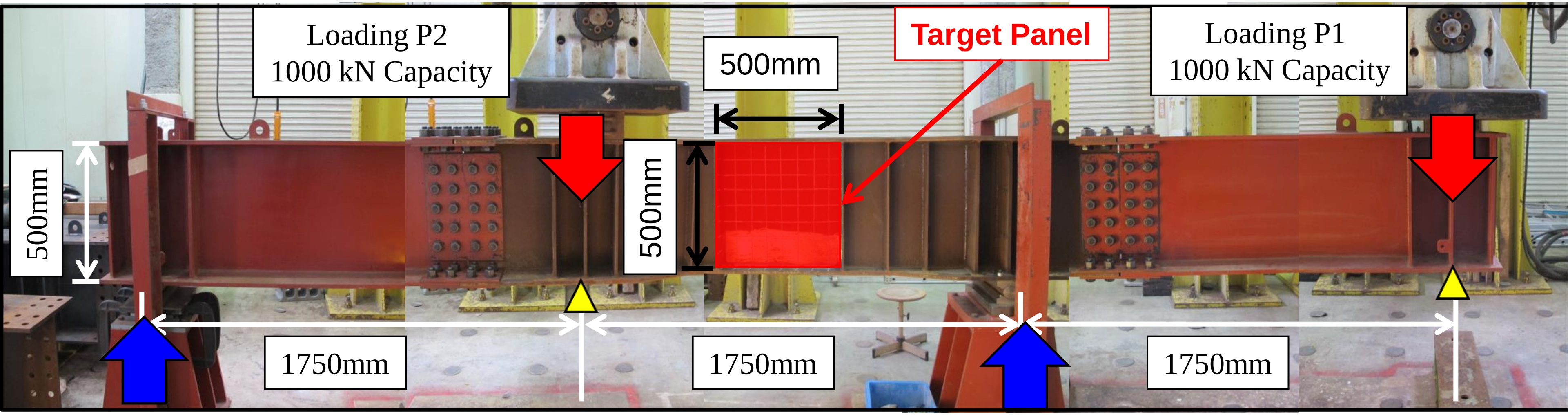
1: Corrosion at steel bridge girder end which affects ultimate shear capacity.
2: Sudden drop of shear capacity after retrofitting by CFRP.

1.2. Purpose:

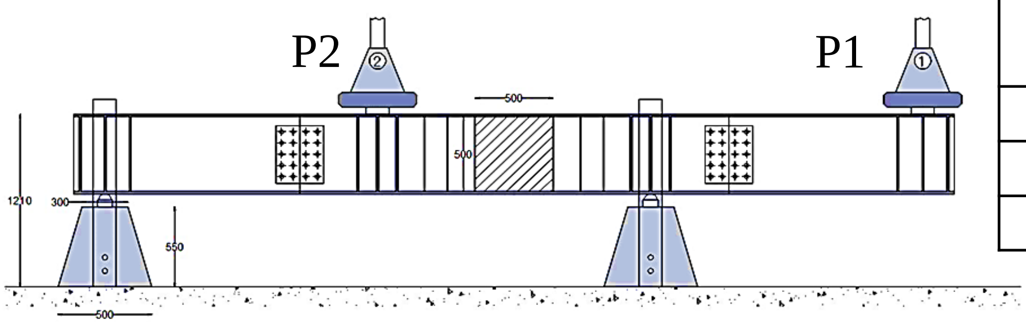
1: Increase ultimate shear load capacity of corroded steel girder end.
2: Create a smoother failure in the post buckling condition.
3: Use less amount of CFRP for retrofitting purposes.

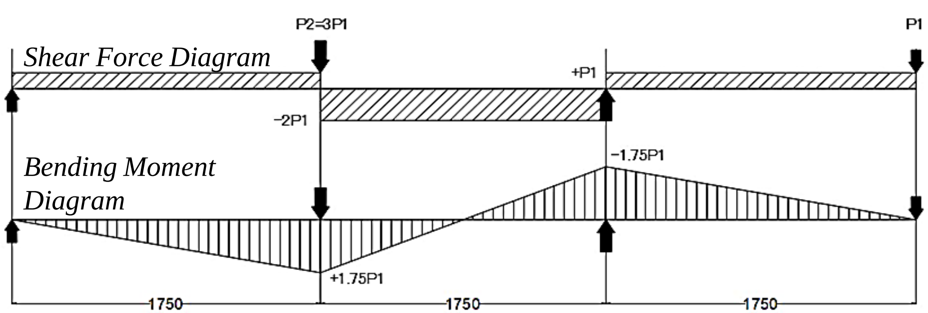
Keywords: Corrosion, Carbon Fiber Reinforced Polymer, Repair, Steel bridge

2. Methodology:



Experimental Setup





Shear Force and Bending Moment Diagrams

Material Properties

Material	Yield Strength (MPa)	Tensile Strength (MPa)	Modulus of Elasticity (MPa)
Steel	328	-	$2.0x10^5$
CFRP	-	3400	$2.1x10^5$
Polyurea (FU-Z)	-	8	55-75

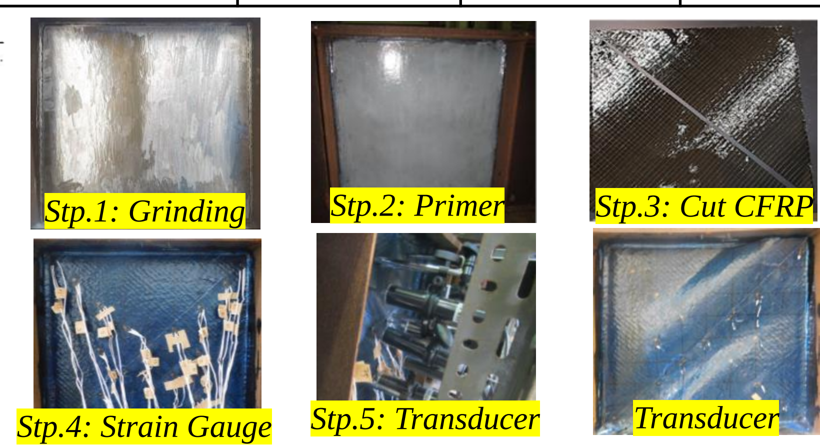
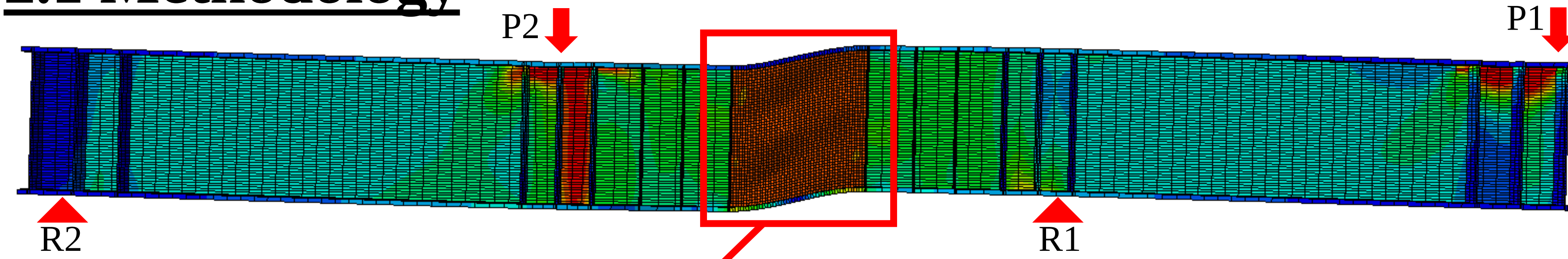
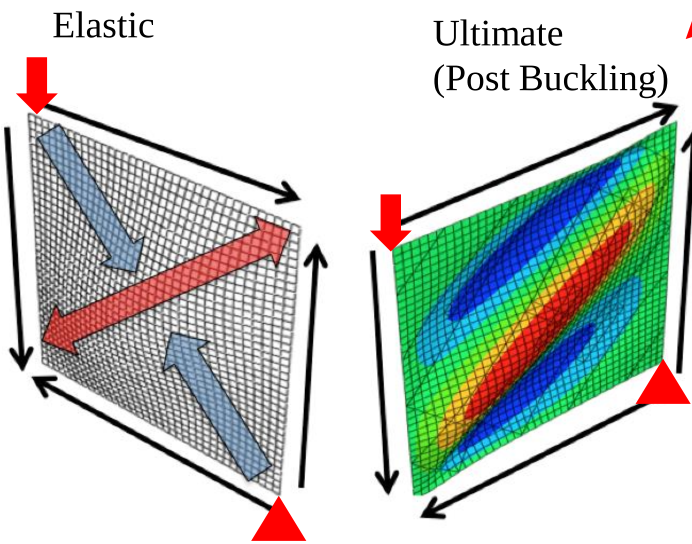


Figure.2 Target Plate Preparation Process

2.1 Methodology



FEM Analysis



Formation of Tensile Diagonal

$$V_u = V_y * \left\{ \frac{\tau_{cr}}{\tau_y} + \frac{\sqrt{3}}{2} * \frac{\left(1-\frac{\tau_{cr}}{\tau_y}\right)}{\sqrt{1+\left(\frac{a}{b}\right)^2}} \right\}$$

Theoretical Ultimate Shear

$$\tau_{cr} = \frac{kE\pi^2}{12(1-v^2)} * \left(\frac{t}{b}\right)^2$$

Theoretical Shear Buckling

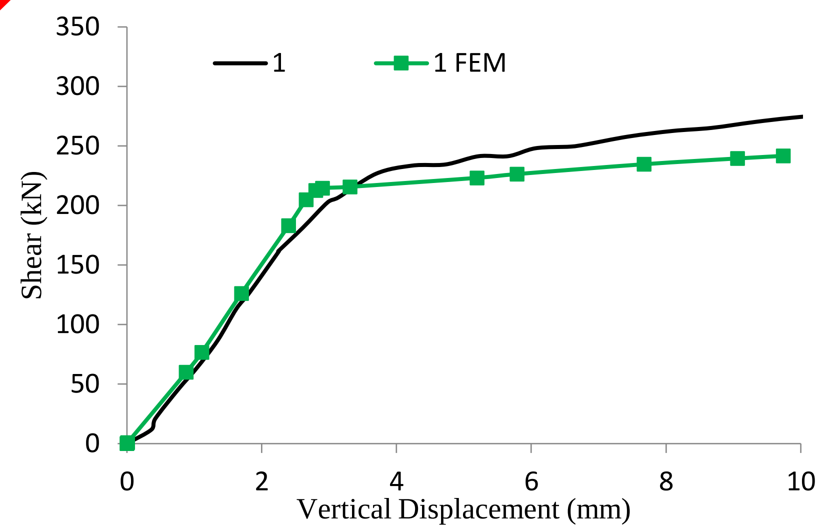


Figure.5 FEM Model Validation

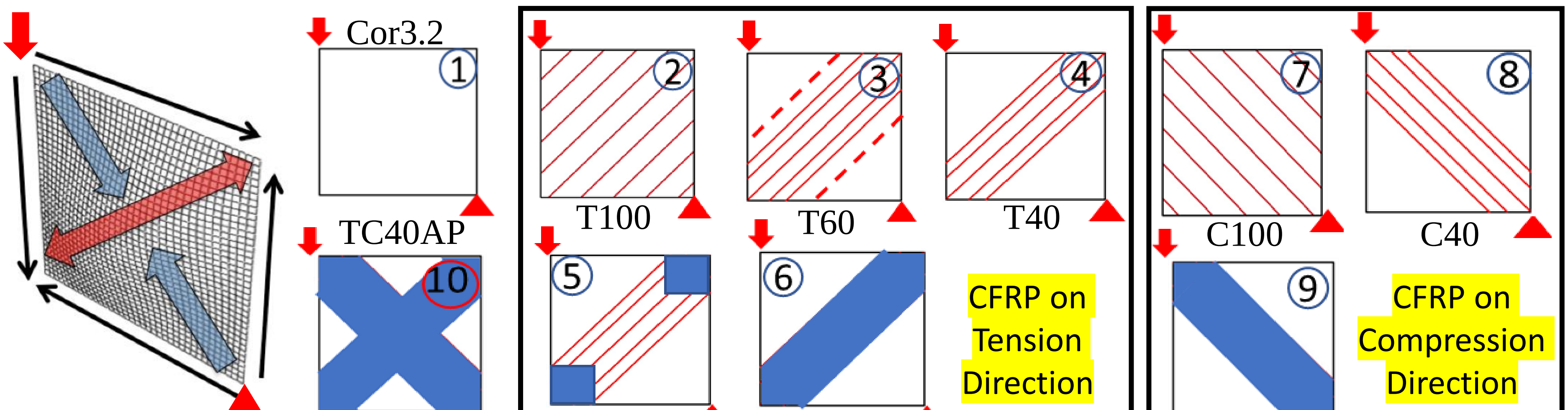
FEM Parameters

Case	Name	CFRP Layers on Each Face of Web Plate	Web Thickness
1	Cor3.2	-	3.2 mm
2	Tar4.0	-	4.0 mm
4	T40	2+2	3.467 mm
5	T40/4	4+4	3.734 mm
6	T40/6	6+6	4.0 mm

3. Results

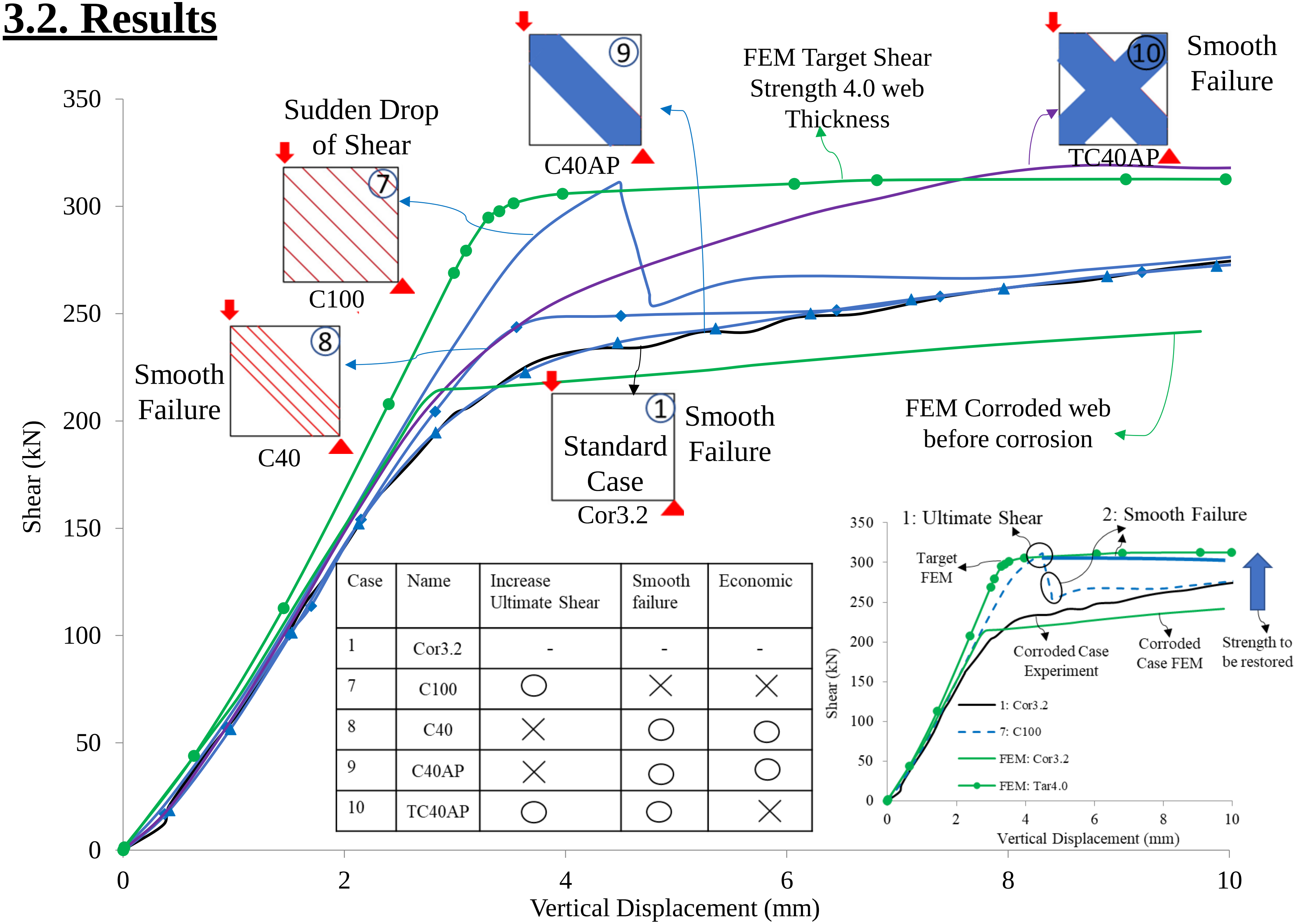
Experimental Parameters

Case	Name (for example: Ten=Tension / 100% = CFRP Coverage of Plate) AP= all polyurea	CFRP Layers on Each Face of Web Plate	Adhesive
1	Cor3.2	-	-
2	T100	2+2	Epoxy Resin
3	T60	2+2	Epoxy Resin
4	T40	2+2	Epoxy Resin
5	T40P	2+2	Epoxy Resin/End Polyurea
6	T40AP	2+2	Epoxy Resin/ Polyurea
7	C100	2+2	Epoxy Resin
8	C40	2+2	Epoxy Resin
9	C40AP	2+2	Epoxy Resin/ Polyurea
10	TC40AP	2+2	Epoxy Resin/ Polyurea



Experimental Figures

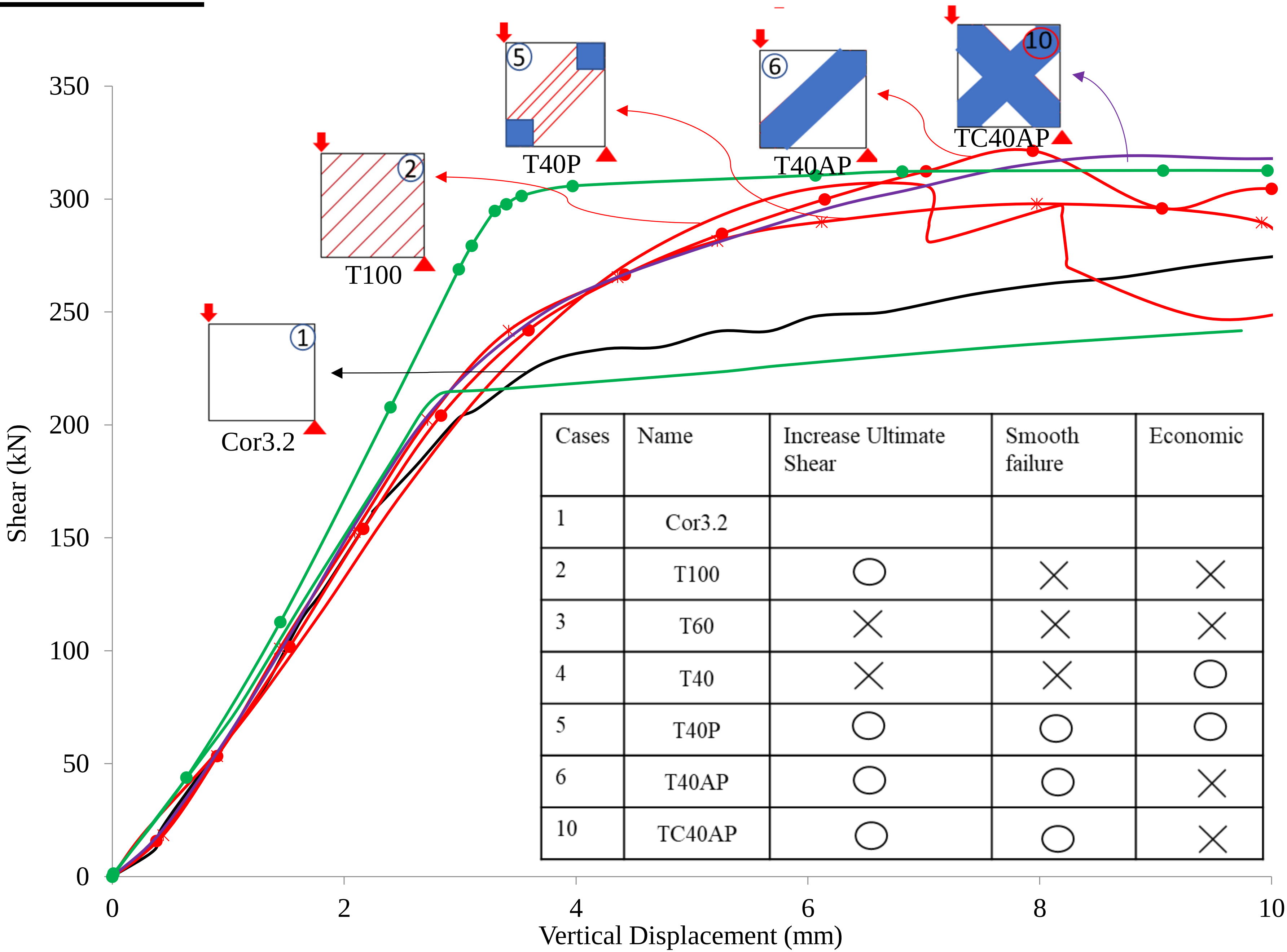
3.2. Results



Case	Name	Increase Ultimate Shear	Smooth failure	Economic
1	Cor3.2	-	-	-
7	C100	○	×	×
8	C40	×	○	○
9	C40AP	×	○	○
10	TC40AP	○	○	×

Figure.7 CFRP Application on Compression Direction of Web

3.1. Results



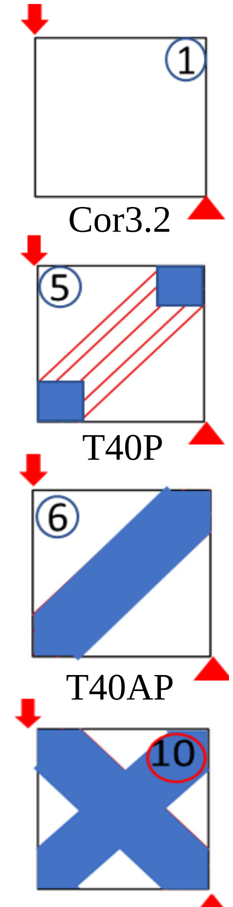
Cases	Name	Increase Ultimate Shear	Smooth failure	Economic
1	Cor3.2			
2	T100	○	×	×
3	T60	×	×	×
4	T40	×	×	○
5	T40P	○	○	○
6	T40AP	○	○	×
10	TC40AP	○	○	×

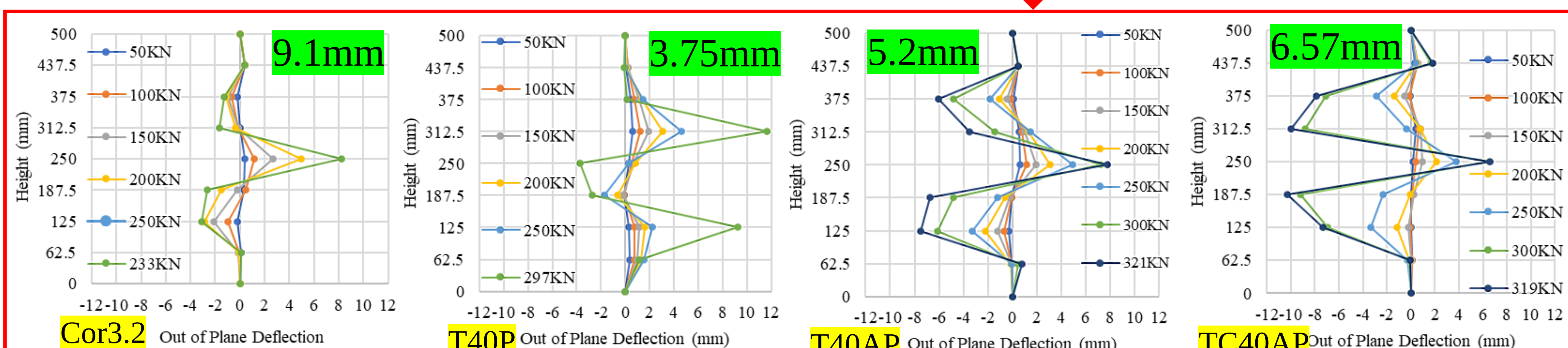
Figure.6 CFRP Application on Tension Direction of Web

3.4. Results

Table.2 Strength Analysis

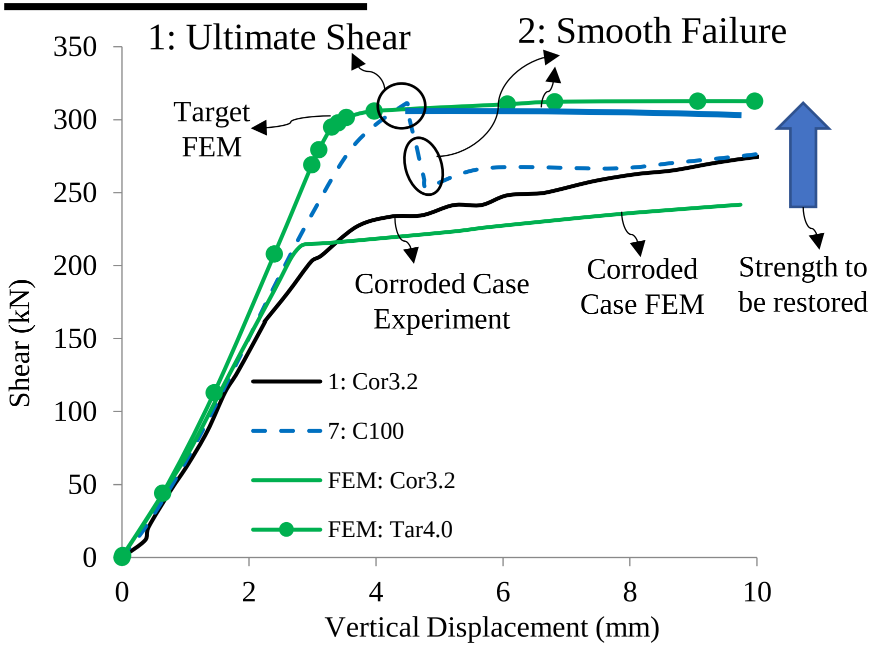
Case	Name (for example: Ten=Tension / 100% = CFRP Coverage of Plate)	Ultimate Shear (KN)	Vertical Displacement and Ultimate Shear (mm)	Shear Strength Added Compared to Corroded Specimen	Max out of plain deflection (mm)	Increase in Stiffness compared to Corroded Specimen (%)
1	Cor3.2	233	5.12	1.0	9.1	1.0
2	T100	306	6.00	1.3	-7.35	1.0
3	T60	282	5.77	1.2	4.97	1.0
4	T40	271	4.54	1.2	2.25	35.5
5	T40P	297	6.12	1.3	3.75	37.9
6	T40AP	321	7.94	1.4	5.2	42.7
7	C100	311	4.47	1.3	5.20	48.5
8	C40	251	6.45	1.1	7.98	36.9
9	C40AP	256	6.2	1.1	9.80	43.5
10	TC40AP	319	8.70	1.4	6.57	51.1





Out of Plain Deflection

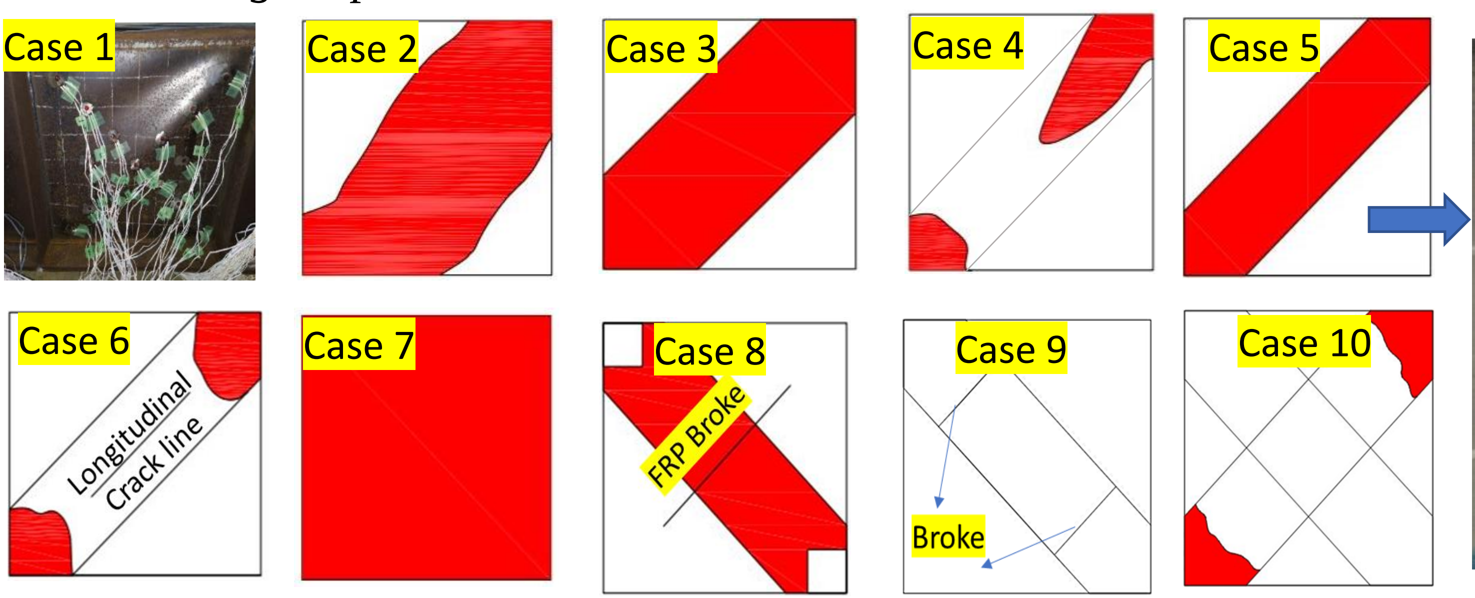
3.4. Results

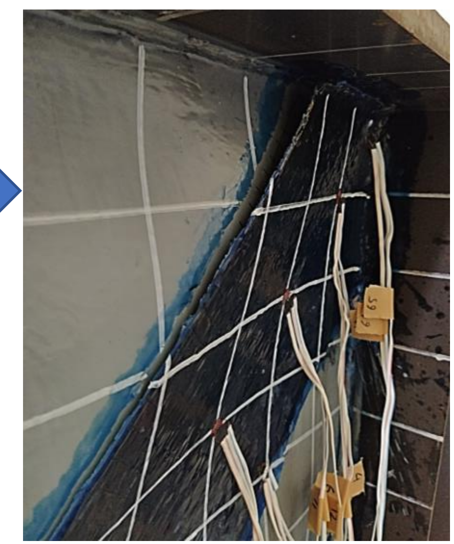


Experiment Evaluation

Cases	Name	Increase Ultimate Shear	Smooth failure	Economic
1	Cor3.2			
2	T100	○	×	×
3	T60	×	×	×
4	T40	×	×	○
5	T40P	○	○	○
6	T40AP	○	○	×
7	C100	○	×	×
8	C40	×	○	○
9	C40AP	×	○	○
10	TC40AP	○	○	×

Delaminating shapes

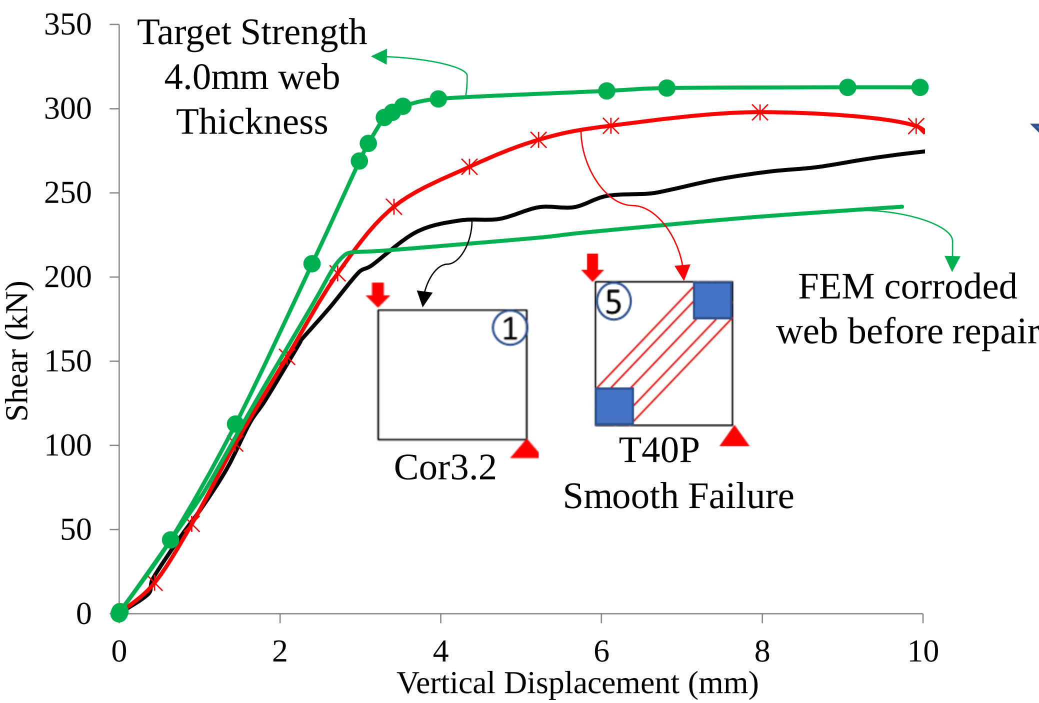




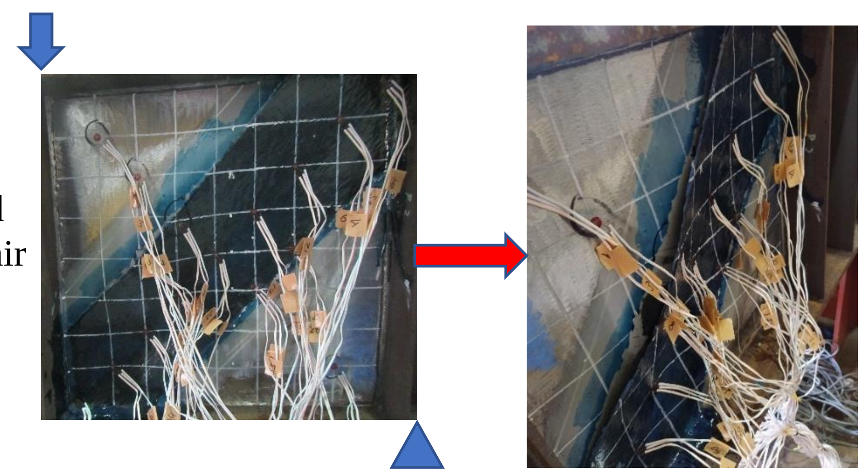
After Peek Performance

4. Conclusion

1. The maximum out of plane deflection can be controlled by applying the CFRP on tension direction of the plate.
2. Using the CFRP on compression direction of the plate can increase the stiffness as much as 48% compared to untreated web plate.
3. Applying CFRP on 40% of the target web plate area on compression direction is not efficient for increasing ultimate shear strength.
4. Applying CFRP on 40% of the target web plate area on tension direction with polyurea can restore the lost strength and revive it as before corrosion.
5. Finally, applying CFRP on 40% of the target web plate total area with only 12.5% of total polyurea usage on the target plate can restore the lost strength of the target plate and can revive it as before corrosion. And is more cost efficient and time efficient.



Recommended Repair Method



Failure mechanism of the Proposed Repair Method