Finite Element Modeling of Seismic Performance of Low Concrete Strength Exterior Beam-Column Joints

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PRESENTATION OUTLINE

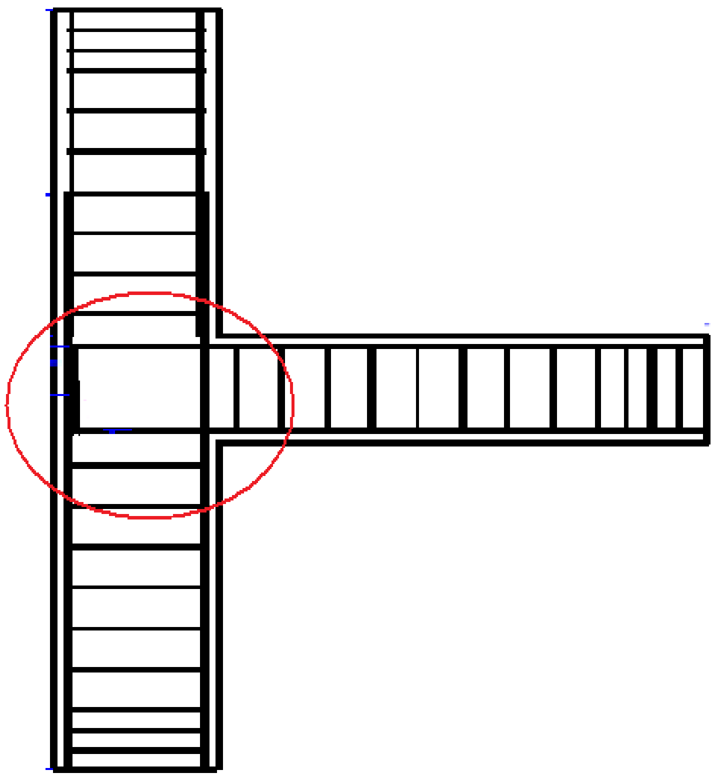
- Introduction
- Beam-Column Joint Test at ITU
- Finite element modeling using DIANA
- Results of Finite Element Analysis
- Conclusions
- Ongoing work at KFUPM

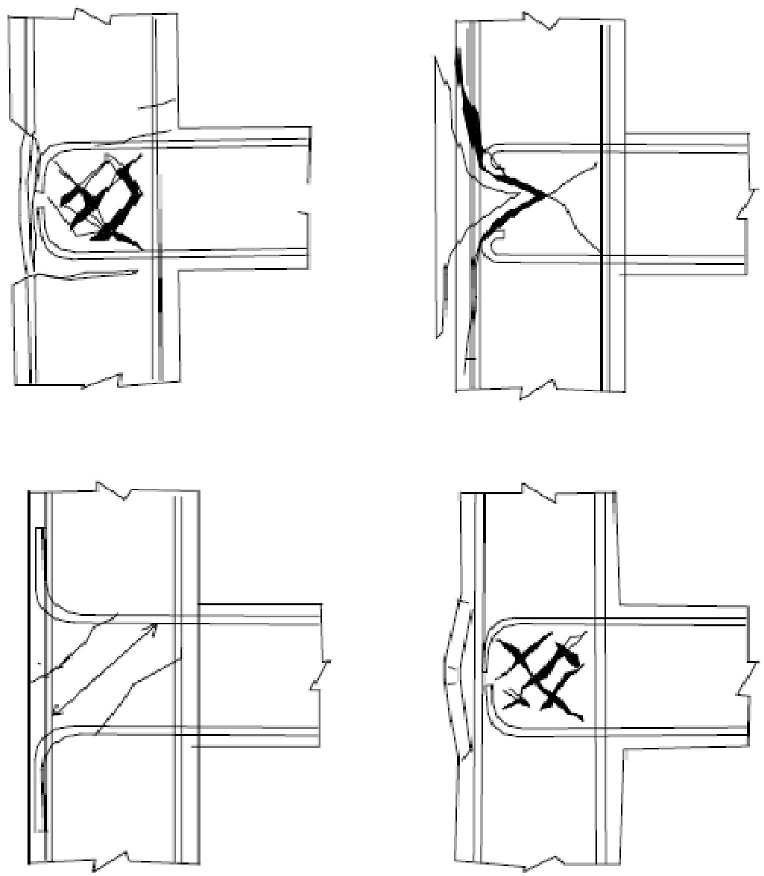
JOINT FAILURE IN BUILDINGS

BACKGROUND

- The Western Region of Saudi Arabia is located in moderately active seismic zone with recent/historical seismic events. Many RC buildings in this region were hitherto designed only for gravity loads using low strength concrete without any ductile detailing of beam-column joints [Alsayed et al]
- An experimental program was conducted at Istanbul Technical University (ITU) on the behavior of exterior beam-column joints subjected to seismic loads. These joints were made with very low strength concrete to simulate the concrete used in reinforced concrete structures in Turkey prior to 1990's. [Bedirhanoglu et al, A.Ilki et al]

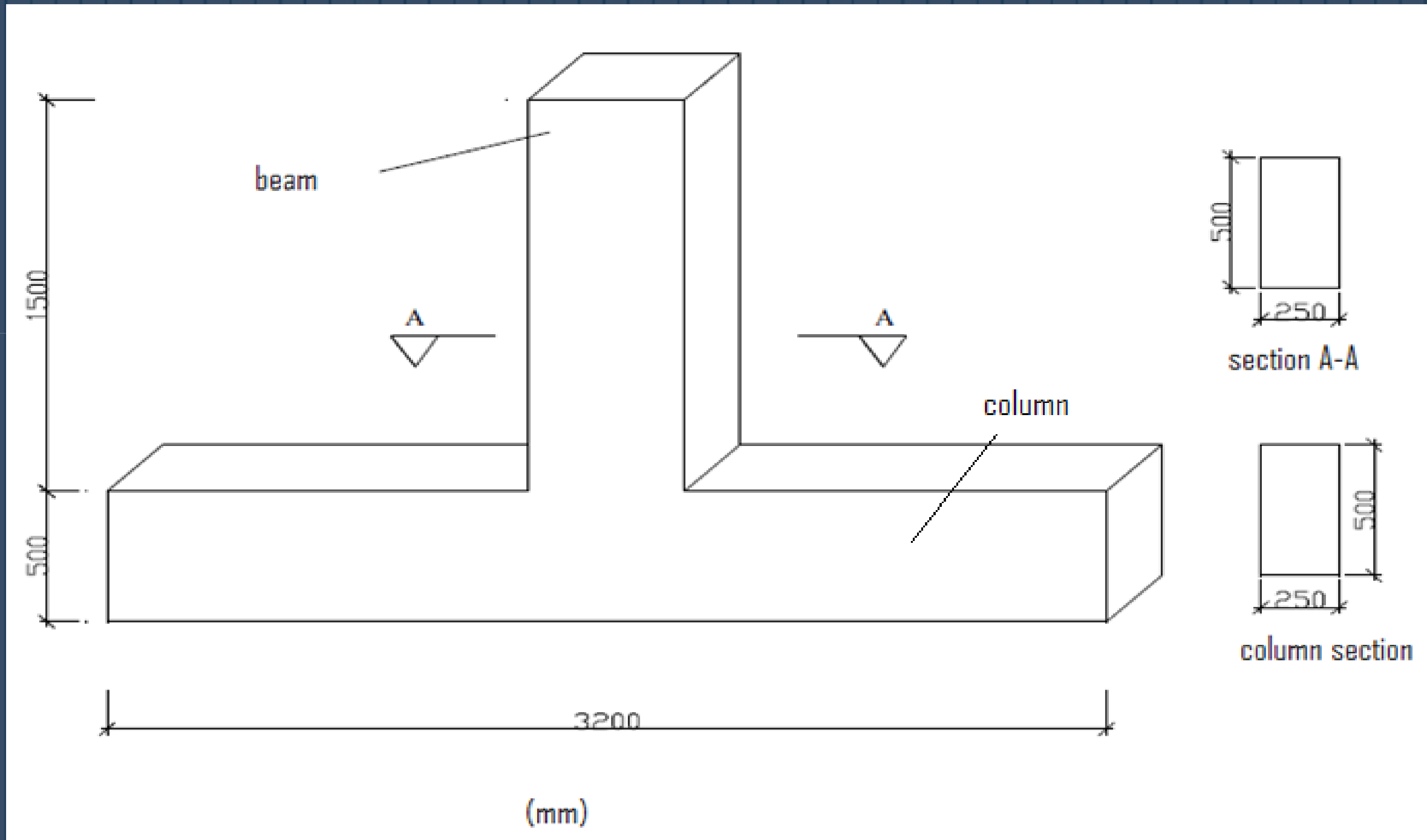
PRE-1990'S DETAILING OF BEAM-COLUMN JOINTS



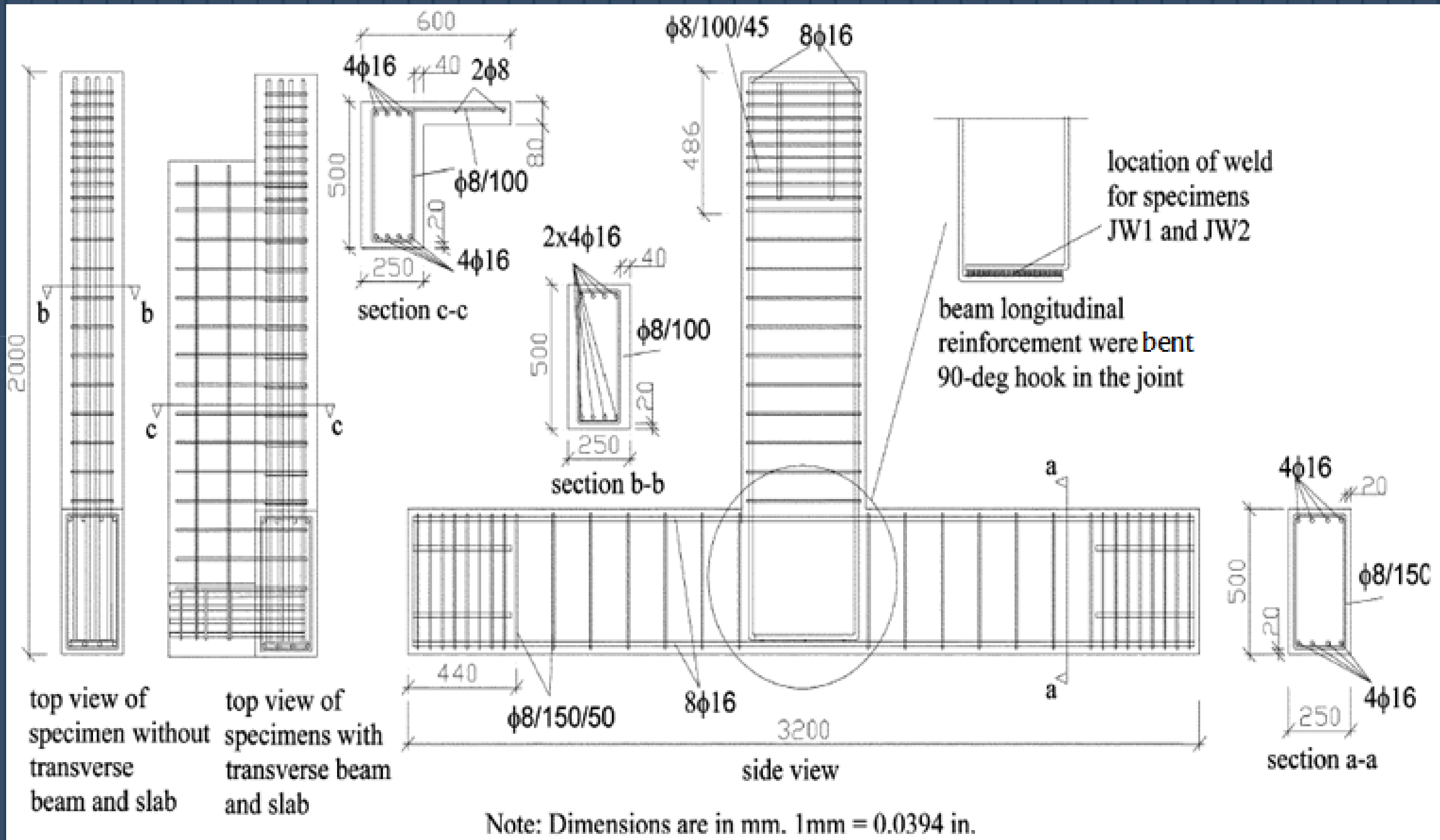


BEAM-COLUMN JOINT TEST AT ITU

GEOMETRY AND REINFORCEMENT DETAILS OF ITU SPECIMEN



GEOMETRY AND REINFORCEMENT DETAILS OF ITU SPECIMEN



MATERIAL PROPERTIES

Mechanical properties of reinforcing bars:

Reinforcement	Dia(mm)	Fy (Mpa)	εy	Fs max (Mpa)	εsmax
Φ16	16	333	0.0017	470	0.2
Φ8	8	315	0.0016	433	0.2

Material properties of concrete:

f'c (Mpa)	Ec (Mpa)
8.3	13000

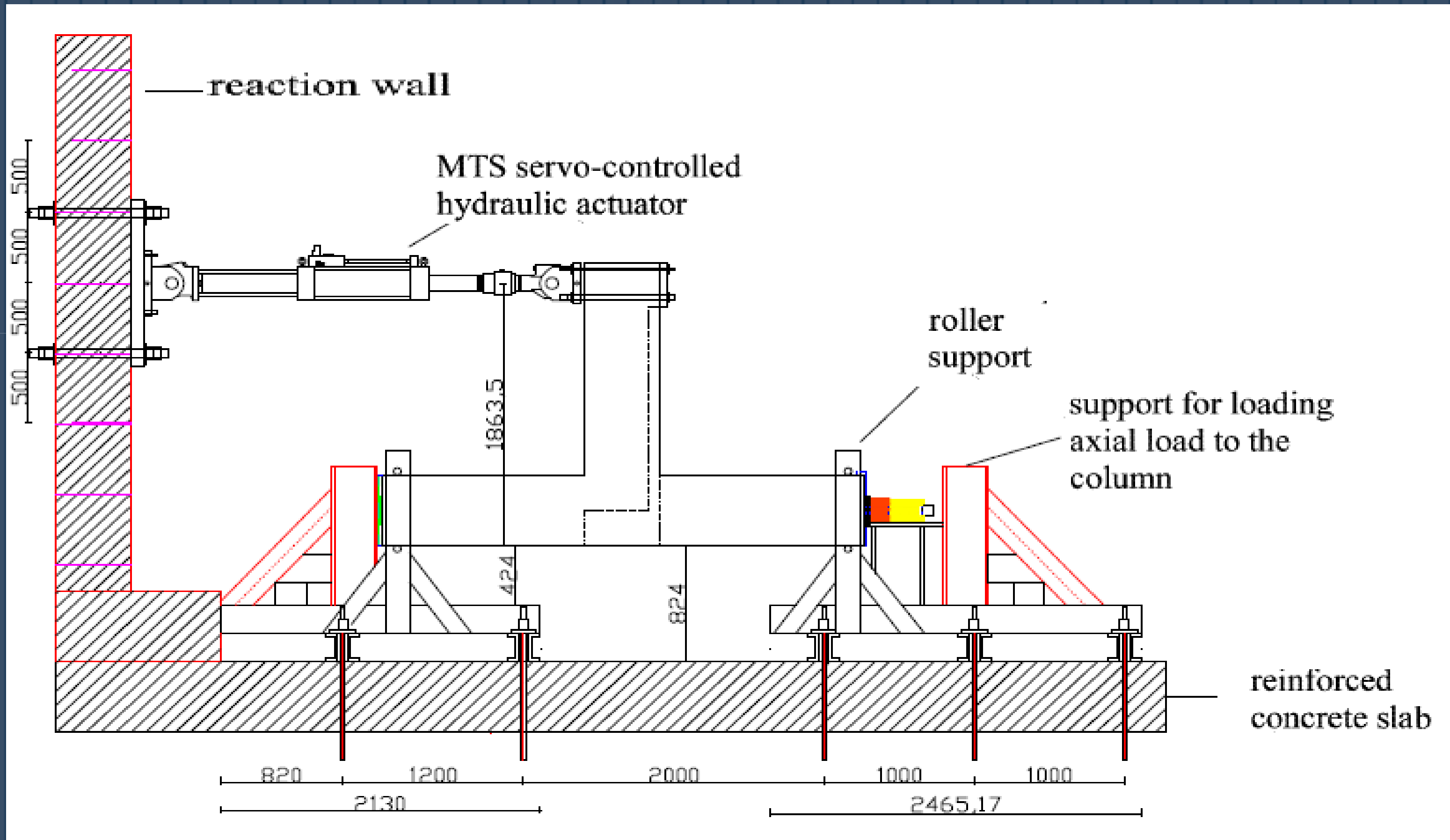
f'c: low strength concrete

SPECIMEN TESTED AT ITU

No.	Specimen	Age, days	f_c', MPa	Joint reinforcement	Transverse beam and slab	Welding of hooks of beam's longitudinal bars at its anchorage in the joint
1	JO1	164	8.3	No	Present	Absent
2	JO2	171	8.3	1ϕ8	Present	Absent
3	JO3	179	8.3	4ϕ8	Present	Absent
4	JO4	143	8.3	No	Present	Absent
5	JO5	156	8.3	No	Absent	Absent
6	JO6	176	8.3	No	Present	Absent
7	JO7	197	8.3	No	Present	Absent
8	JW1	208	8.3	No	Present	Present
9	JW2	230	8.3	No	Present	Present

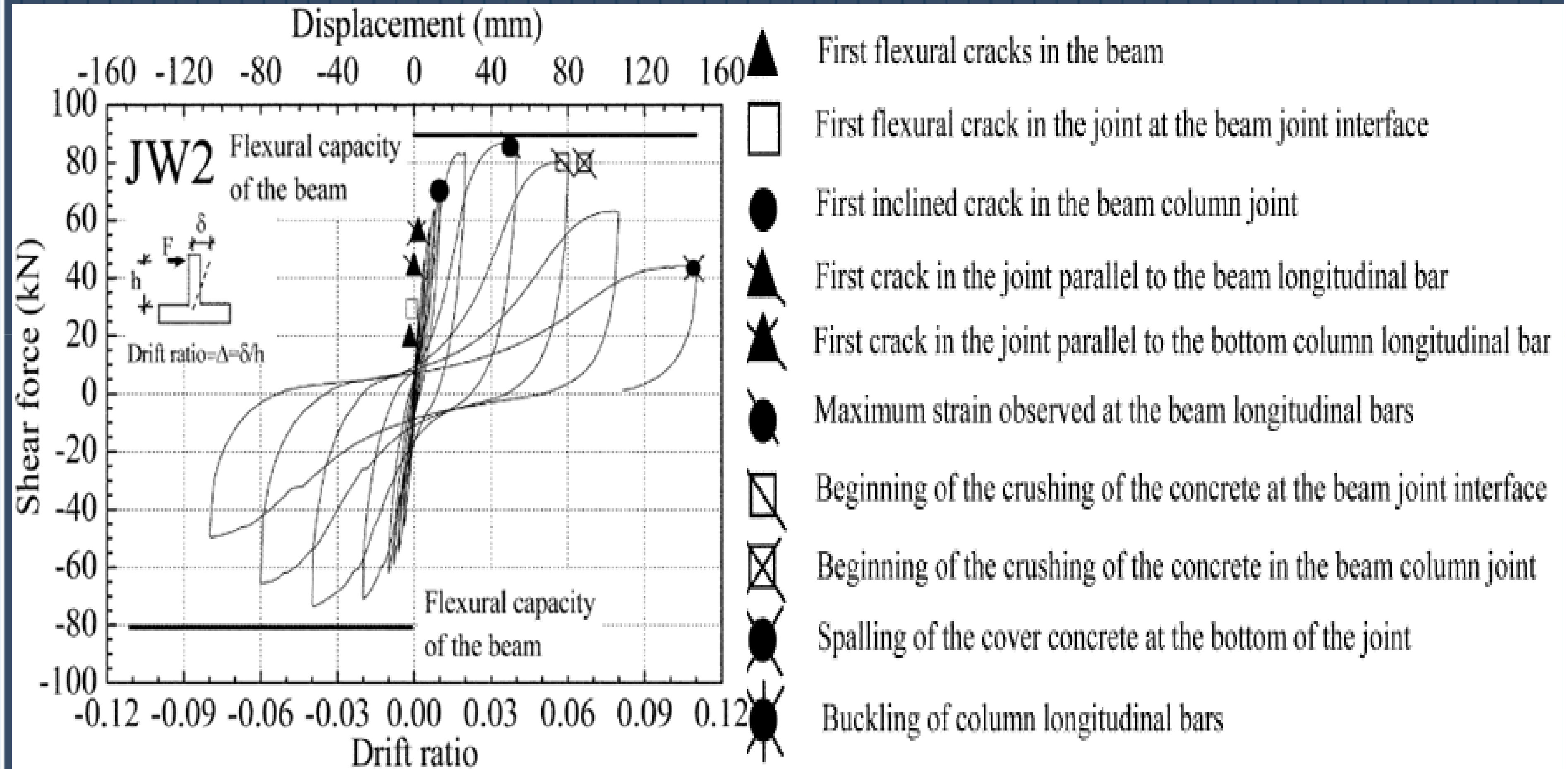
- Test specimens selected for F.E modeling are JW1 and JW2 which are with welded hooks and repaired joints with high strength mortar.

TEST SETUP

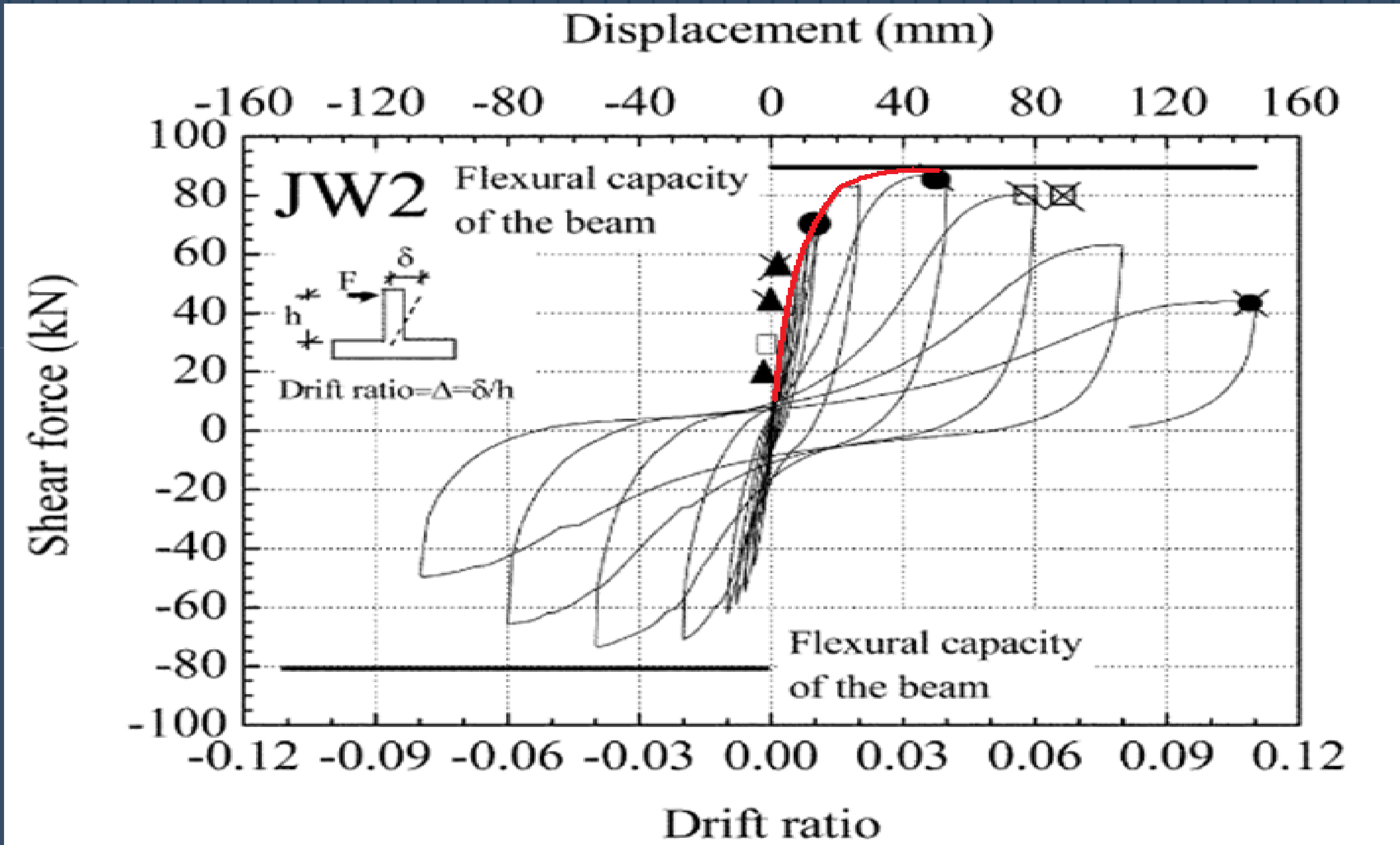


reaction wall
MTS servo-controlled
hydraulic actuator
roller
support
support for loading
axial load to the
column
reinforced
concrete slab
500
500
500
500
1863.5
424
824
820
1200
2000
1000
1000
2130
2465.17

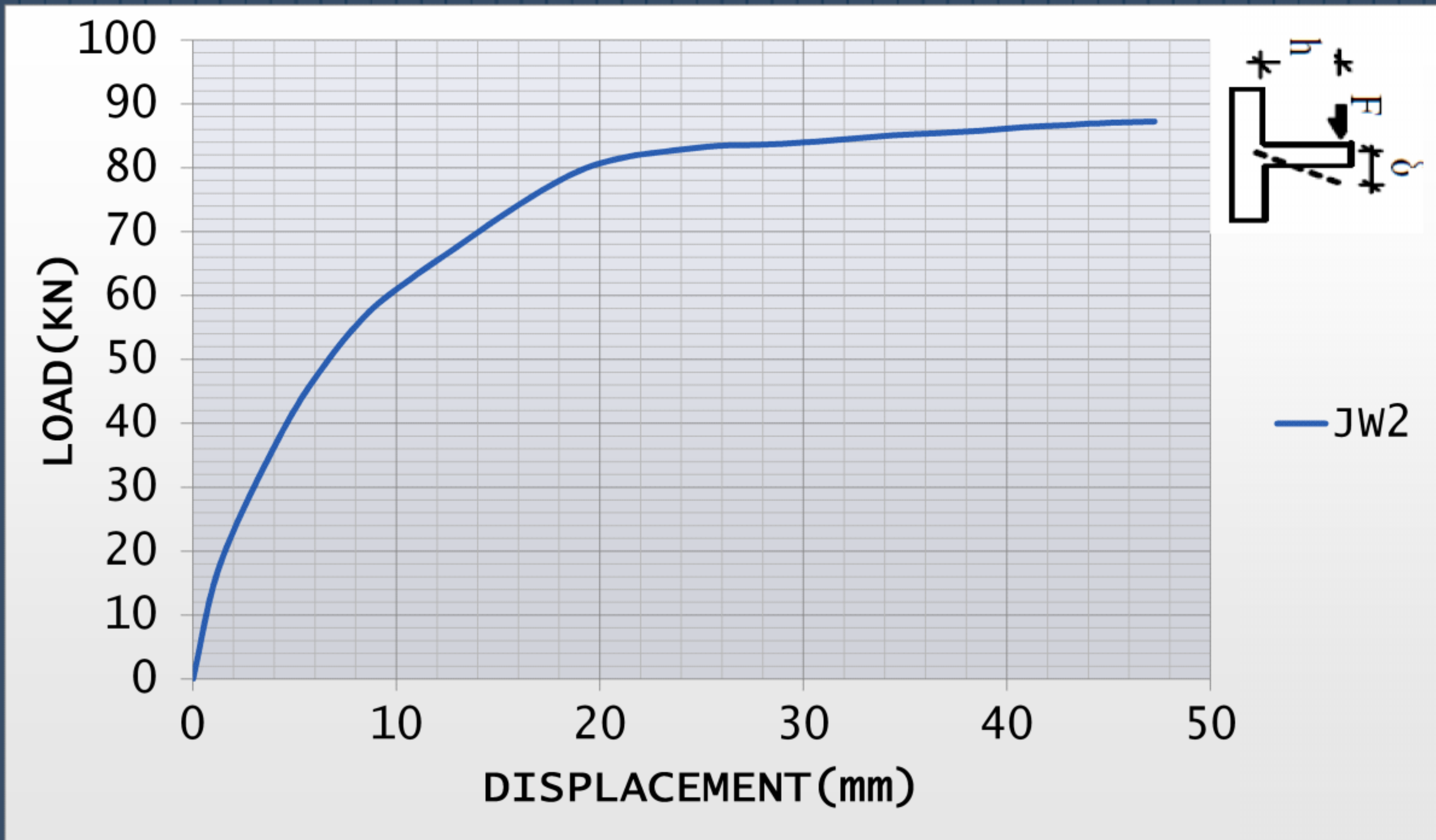
TEST RESULTS FOR JOINT JW2



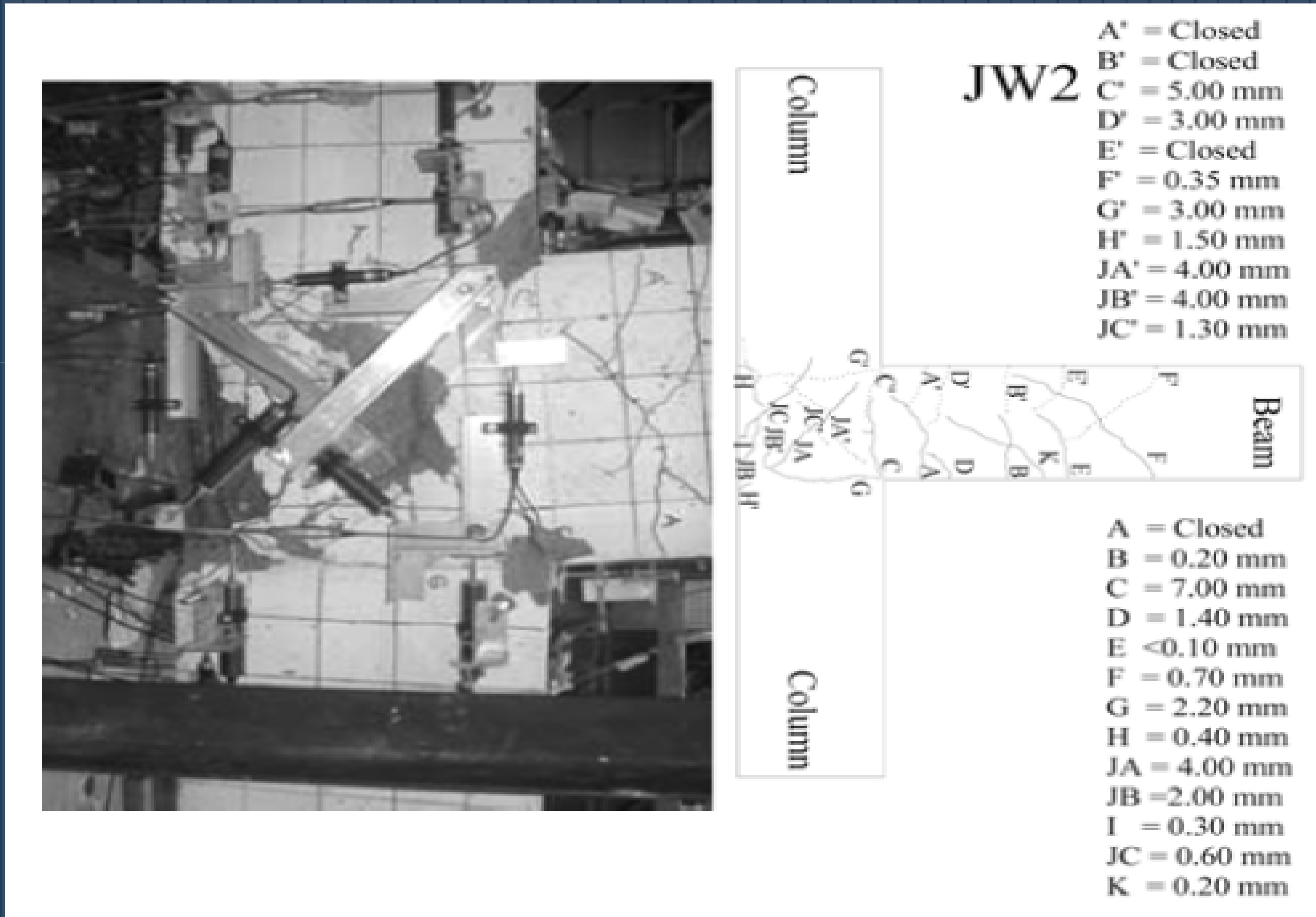
ENVELOPE FOR HYSTERESIS



LOAD VS DISPLACEMENT DIAGRAM FOR JW2



JOINT FAILURE FOR JW2

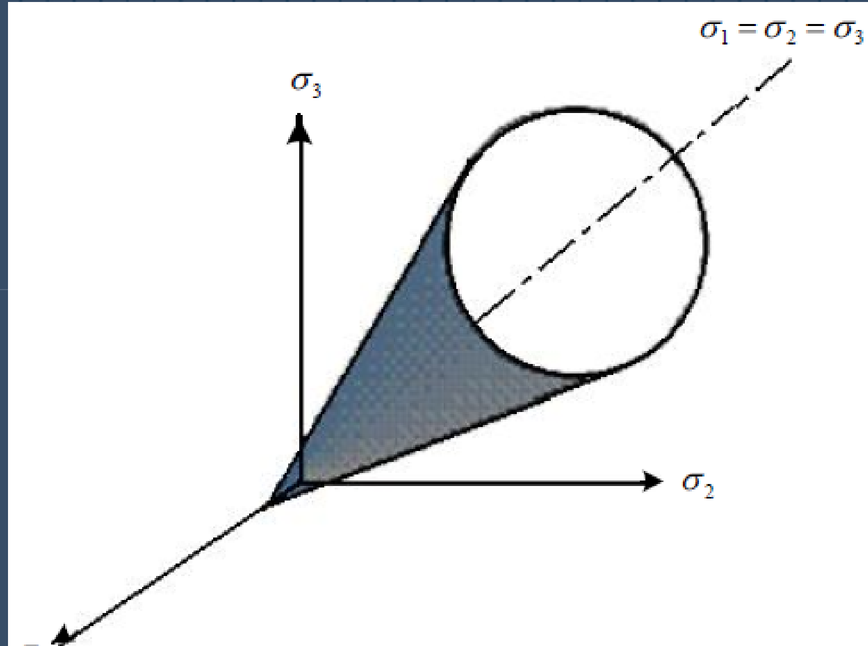


FINITE ELEMENT MODELING

- The commercial F.E software DIANA is used which is well known for modeling concrete structures due to its wide range of concrete material models and advanced numerical tools.
- The non-linear mechanisms that are considered in the modeling are cracking and crushing of concrete and yielding of reinforcement.
- The finite element model is two dimensional consisting of plane stress elements.

MATERIAL CONSTITUTIVE MODELS

- Concrete Plasticity :
- Concrete is modeled as elastic perfectly plastic.
- Drucker-Prager yield criterion is used to model the stress level at which yielding of concrete is initiated.
- The yield surface of Drucker-Prager model is a circular cone which can be related to Mohr-Coulomb by expressing α and k in terms of c and ϕ.
- In Drucker-Prager plasticity model, associated plasticity is established by setting ϕ = ψ.



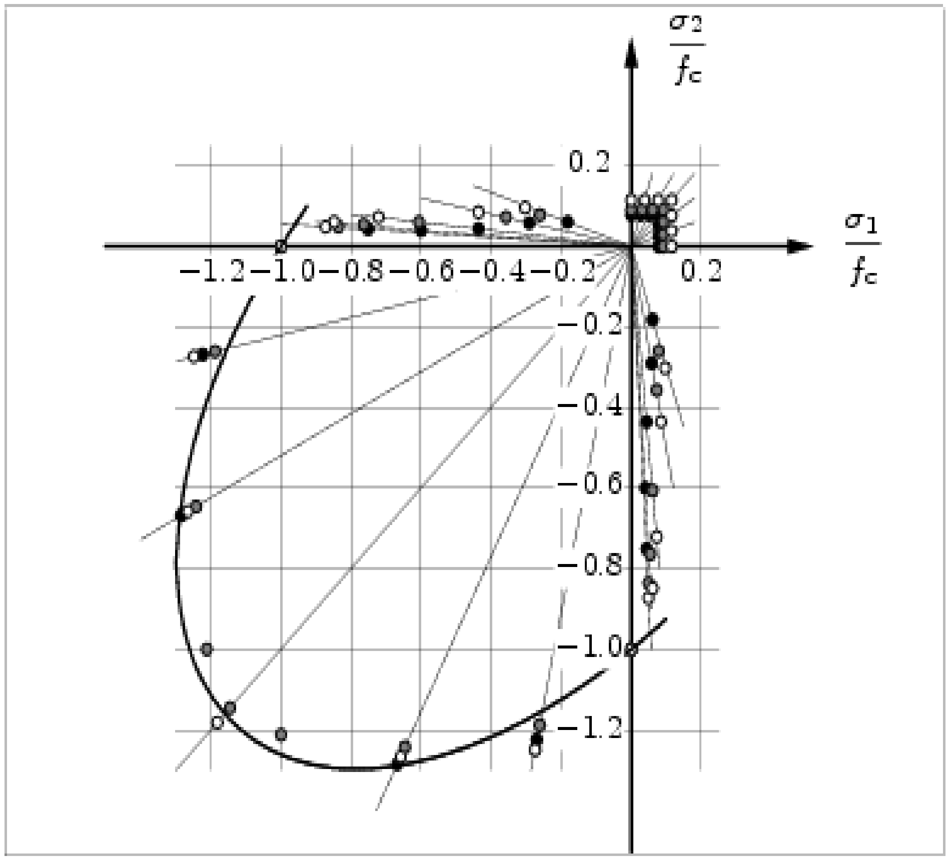
3D Yield Surface of Drucker- Prager

MATERIAL CONSTITUTIVE MODELS

- The cohesion is related to the concrete strength through the relation given by

$$c = f'_c \left[\frac{1-\sin\phi}{2\cos\phi}\right]$$

- For the normal strength quality concrete, the ratio between the biaxial compressive strength and uniaxial compressive strength is approximately 1:1.16 which results in a friction angle ϕ=10deg and cohesion c=0.42f'c

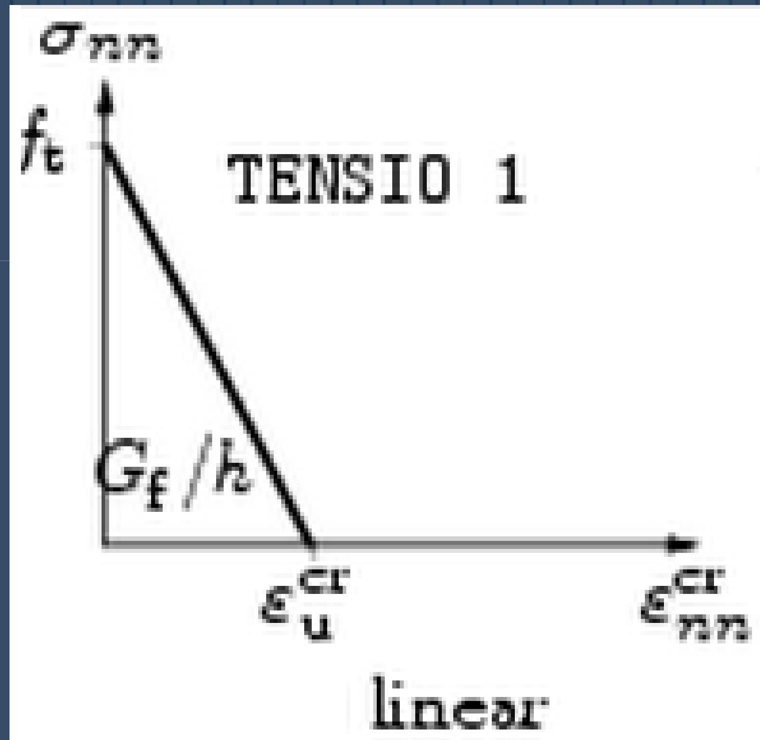


Biaxial strength of plain concrete, Kupfer and Gerstle

MATERIAL CONSTITUTIVE MODELS

- **Concrete cracking:**

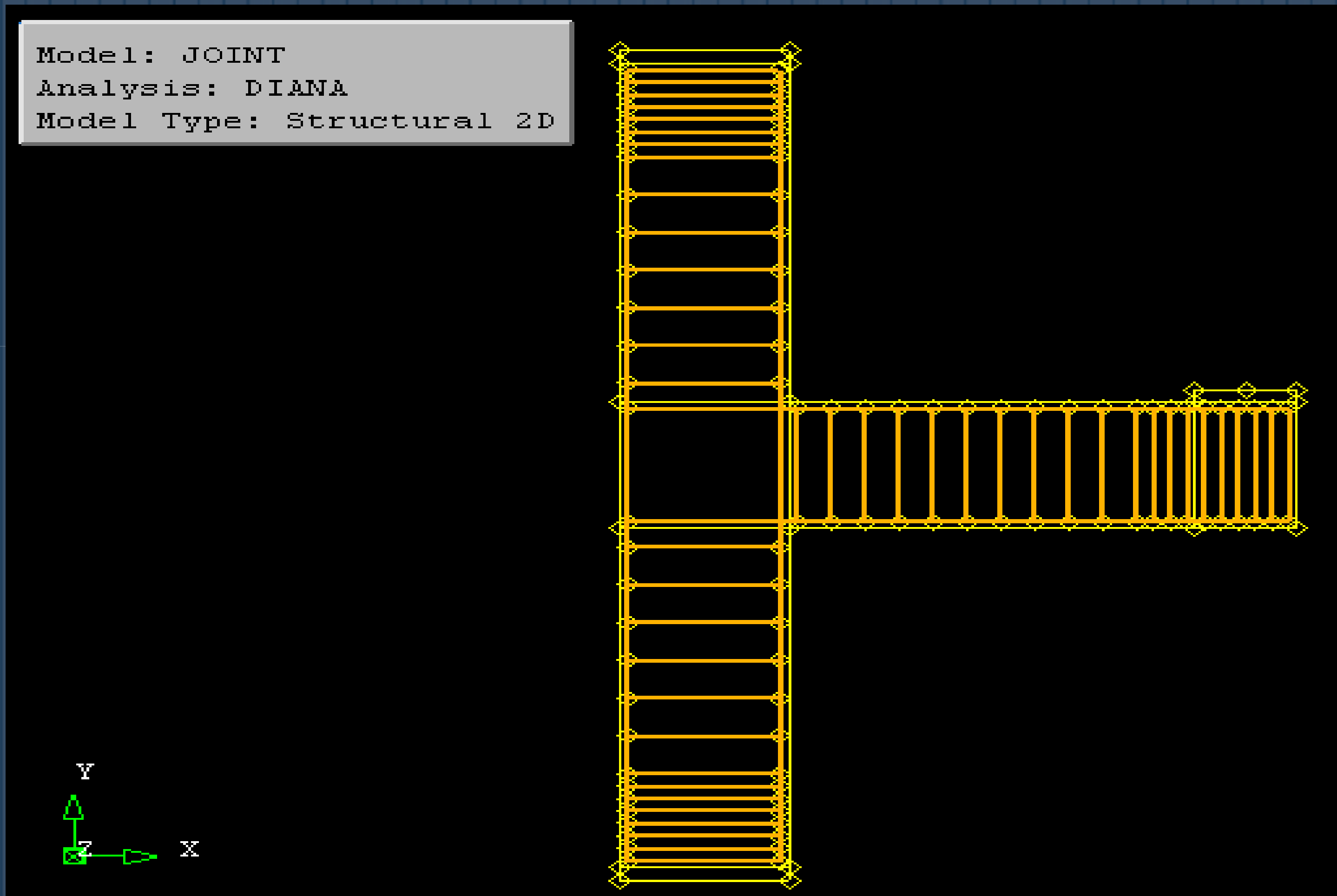
  The cracking of the concrete is specified as a combination of constant tension cut-off, linear tension softening and shear retention.



- **Reinforcement:**

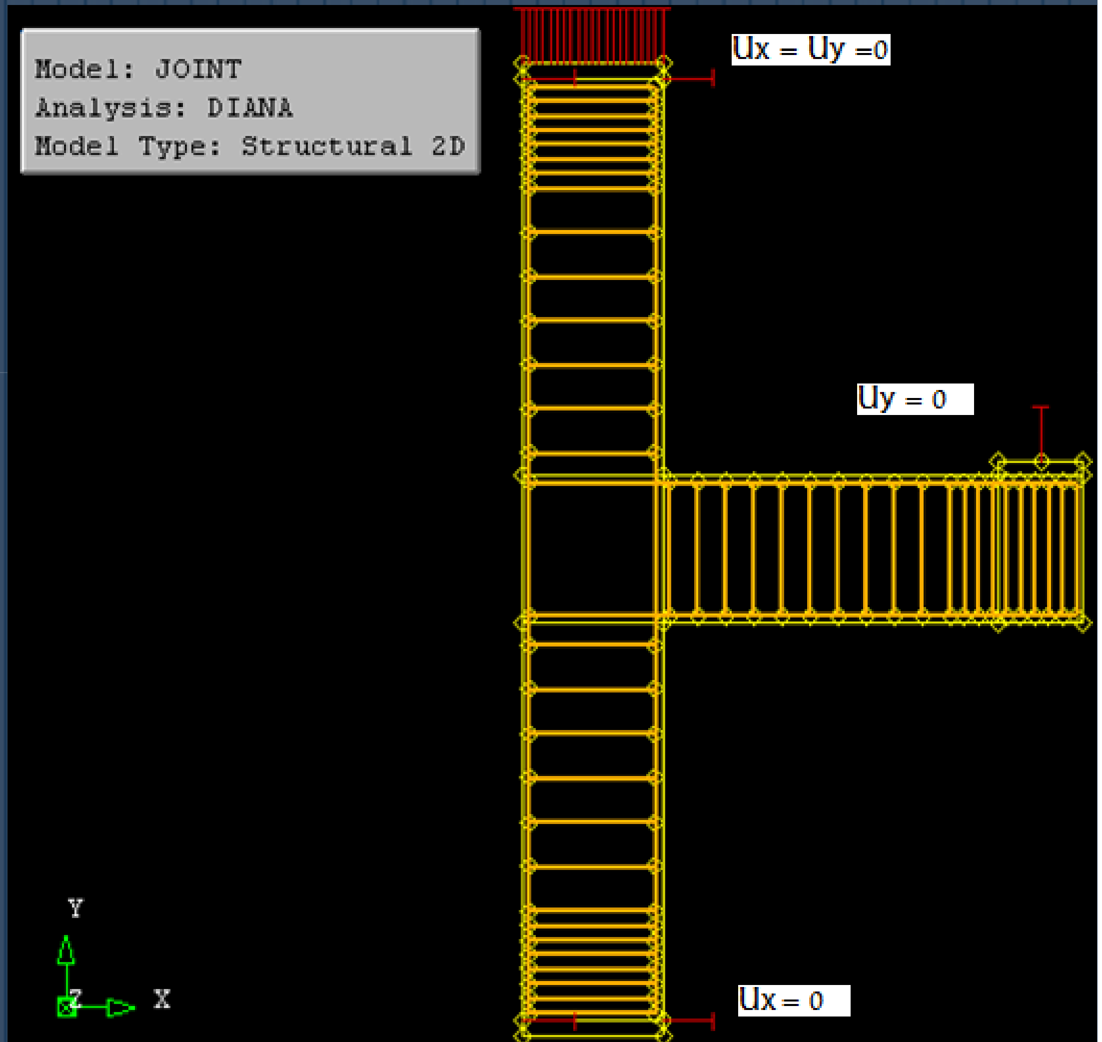
  For reinforcement Von-Mises-Plasticity with work hardening is used.

2-D MODEL WITH REINFORCEMENT

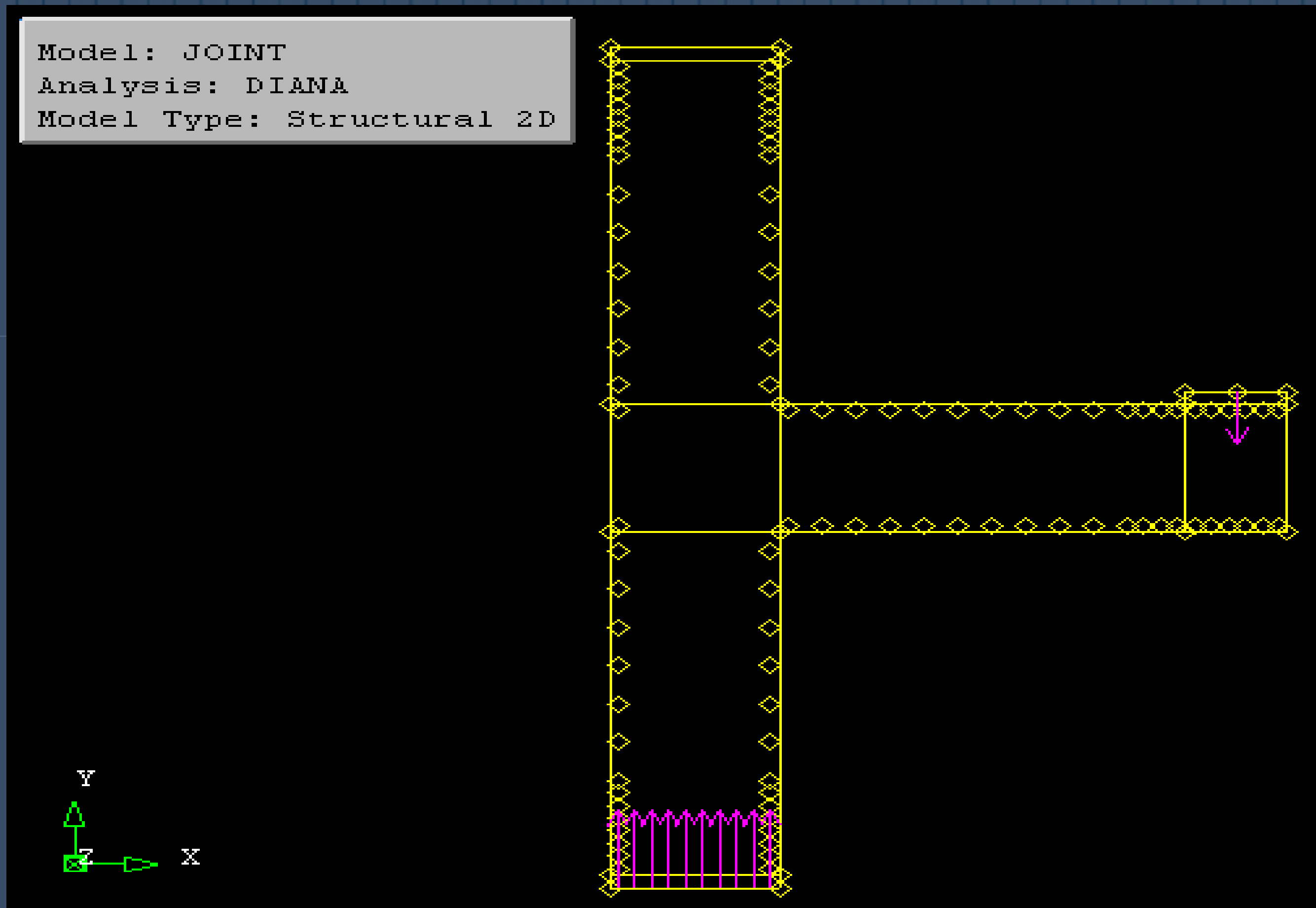


BOUNDARY CONDITIONS AND LOADING DETAILS

- Top end of the column surface is constrained in X and Y direction
- Bottom end of the column is constrained in X axis and free in Y direction due to upward axial pressure (0.125*f’c).
- Near the tip of beam point is constrained in y direction because loading method is displacement control which is 50mm

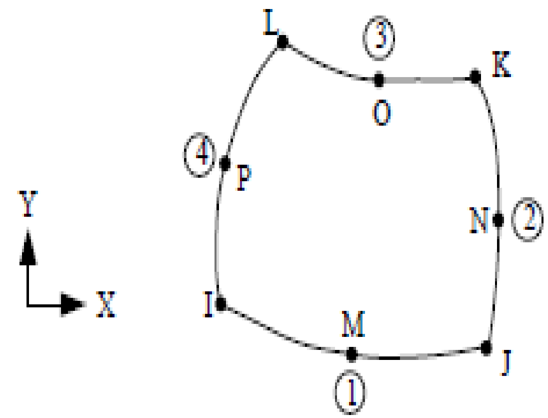


BOUNDARY CONDITIONS AND LOADING DETAILS



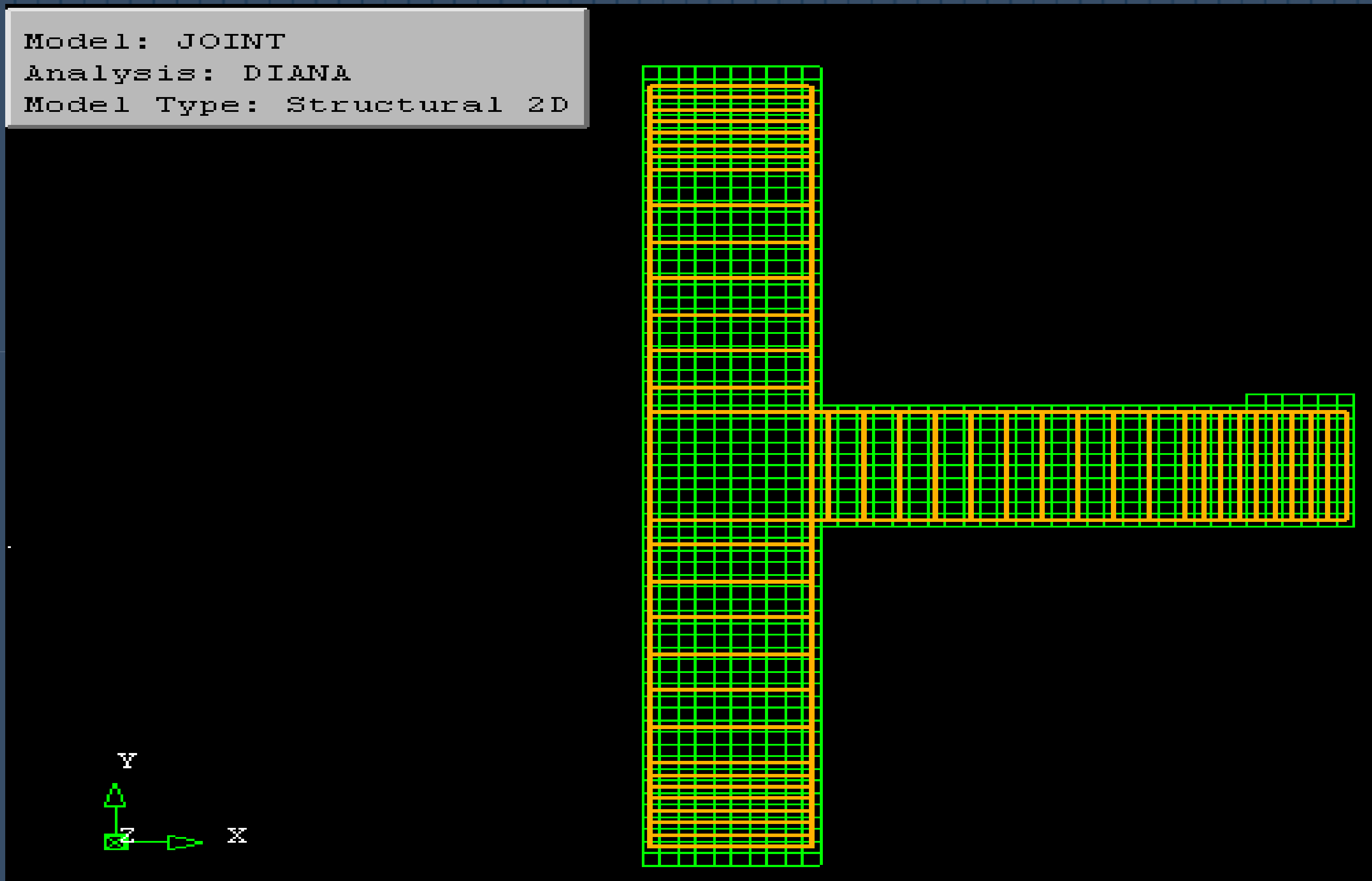
FINITE ELEMENT MESH

- The concrete is modeled by eight-noded quadrilateral isoparametric plane stress element CQ16M.
- The mesh size of concrete element is 50x50 (mm).
- Reinforcements are modeled as embedded reinforcement.



Eight-node Quadrilateral Isoparametric Plane Stress Elements

MESH WITH REINFORCEMENT

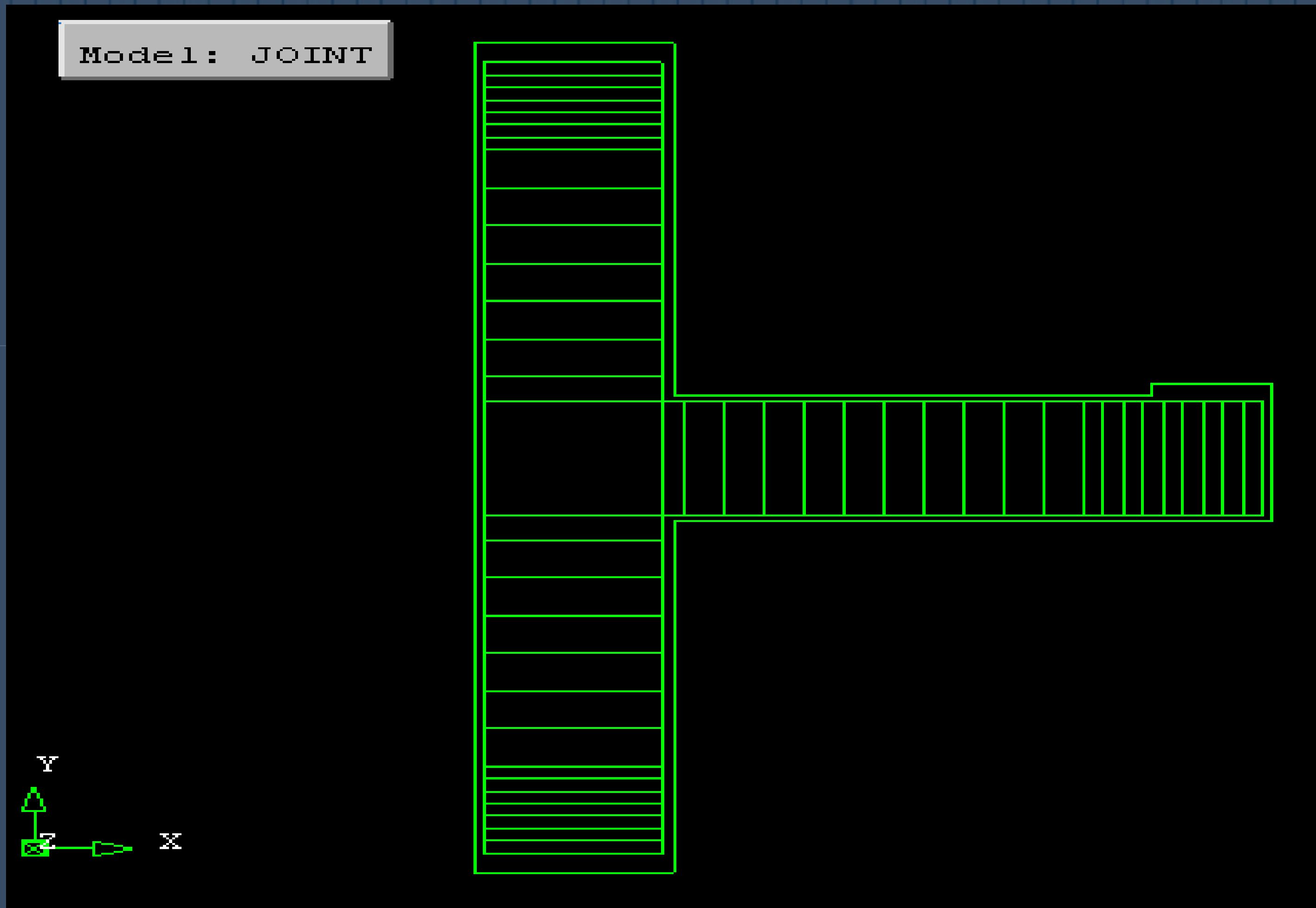


DIANA ANALYSIS

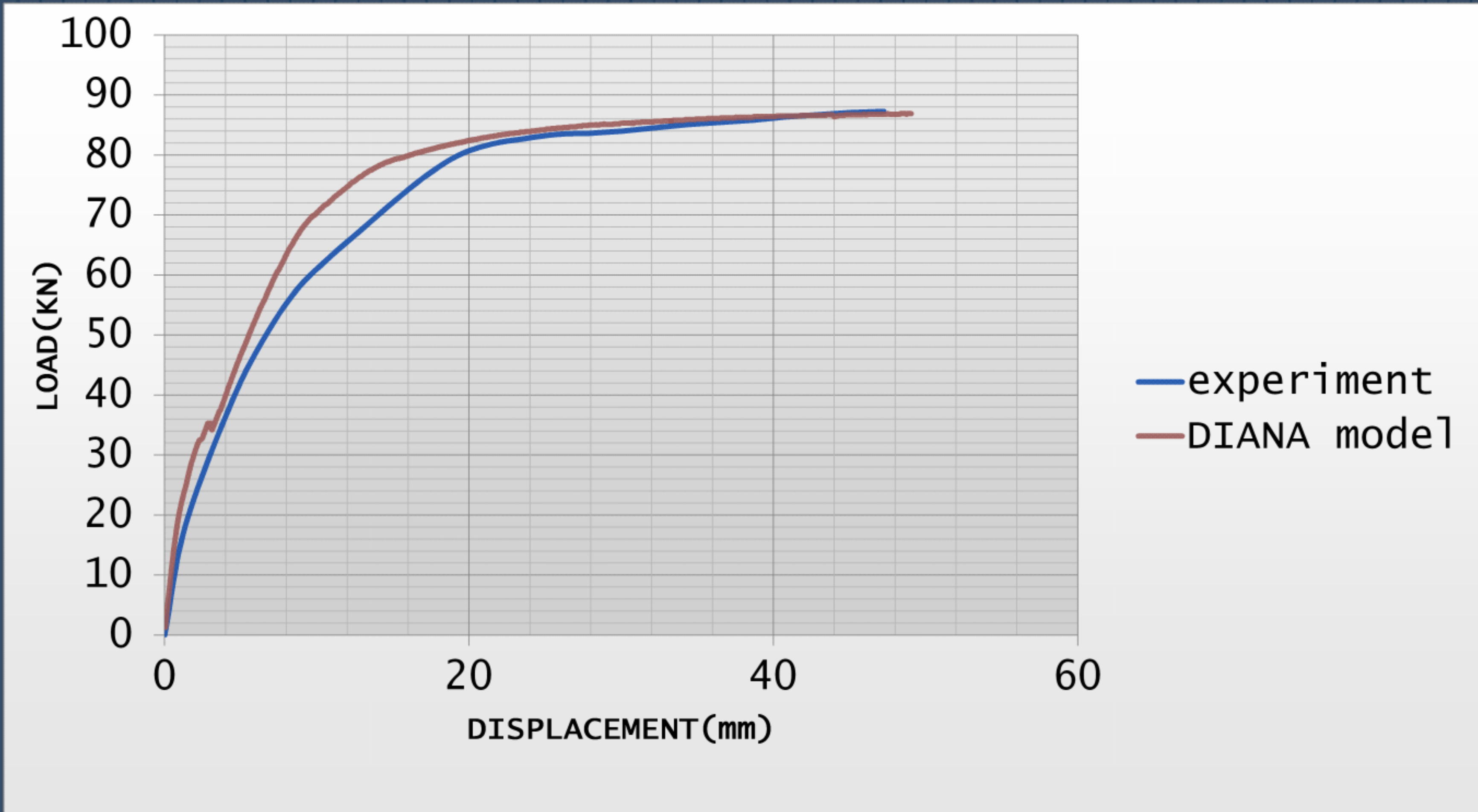
- DIANA needs two files to start the analysis

1. (.dat) file which contains material properties for concrete ft=0.73Mpa at 28 days, c=2.15Mpa (calibrated to match experimental data), $\phi = \psi$=10deg, beta=0.9 (smaller values lead to premature curtailment of P-Δ curve), E=12000Mpa and steel (hardening diagram and modulus of elasticity) , Nodal coordinates , Reinforcement coordinates, Boundary conditions and Load cases.
2. (.com) file where we define the iteration method, step size (load step 0.050mm) and convergence criteria for analysis.

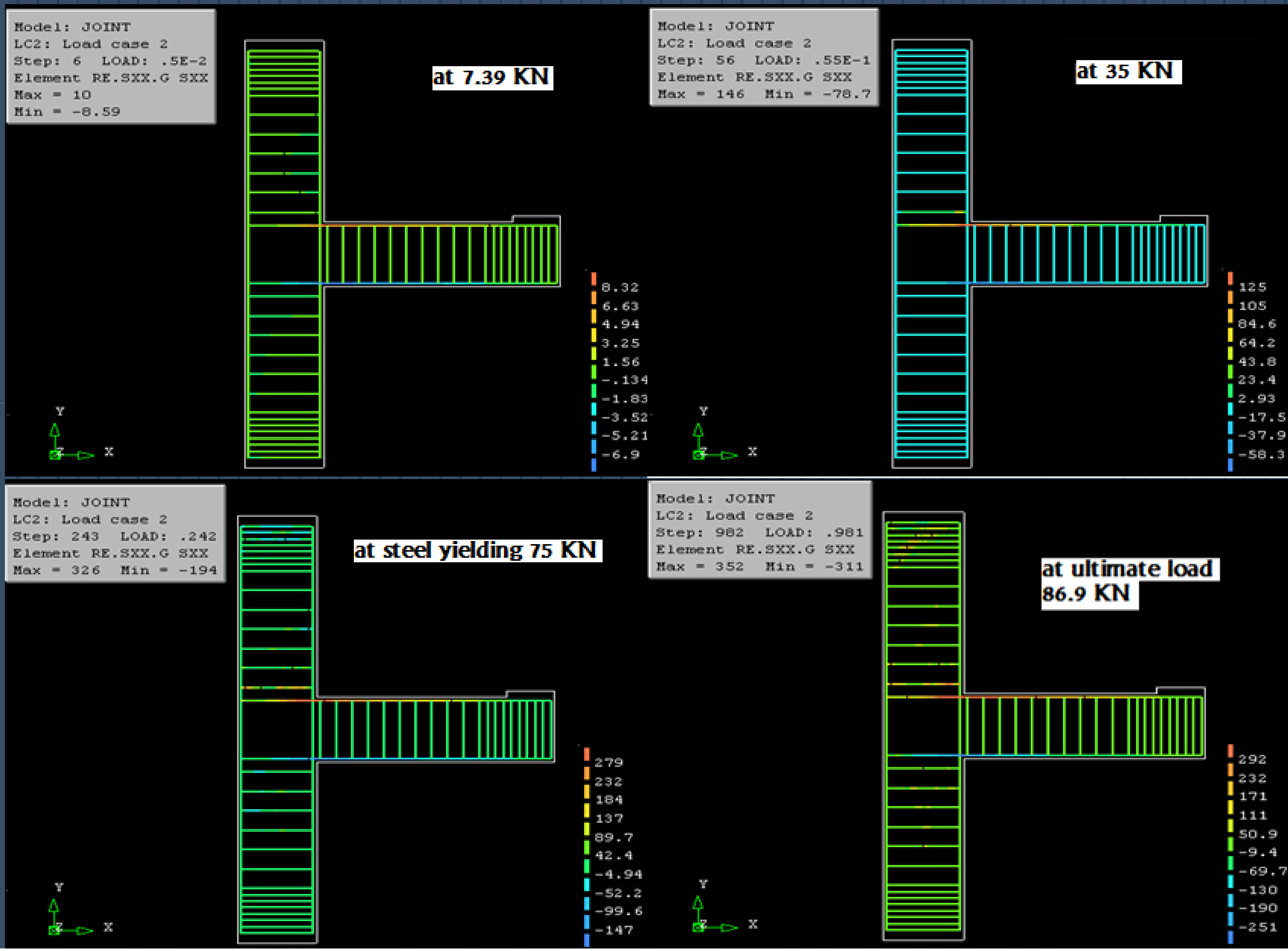
FINITE ELEMENT ANALYSIS RESULTS



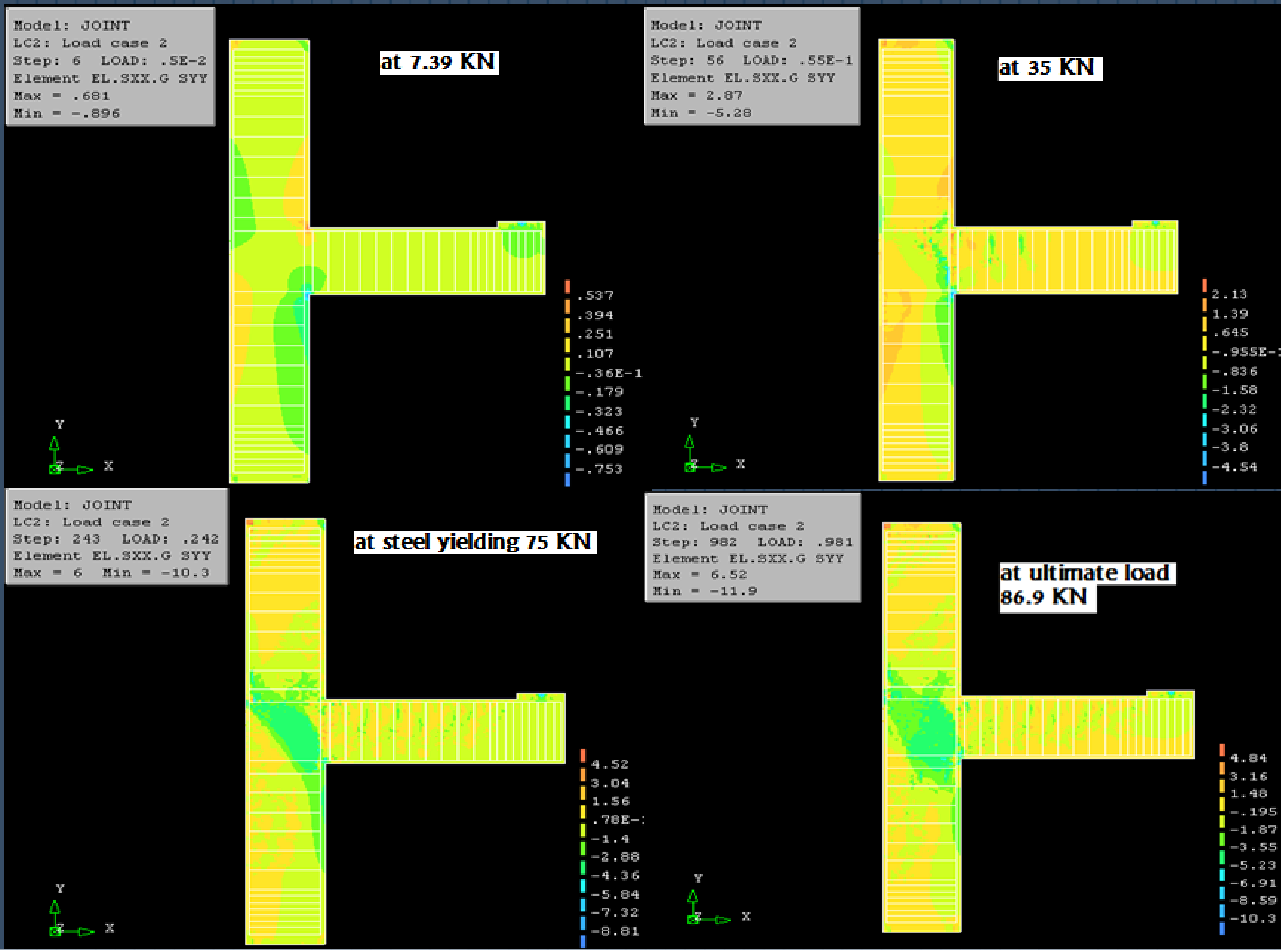
LOAD VS DISPLACEMENT DIAGRAM FOR JW2 AND DIANA MODEL



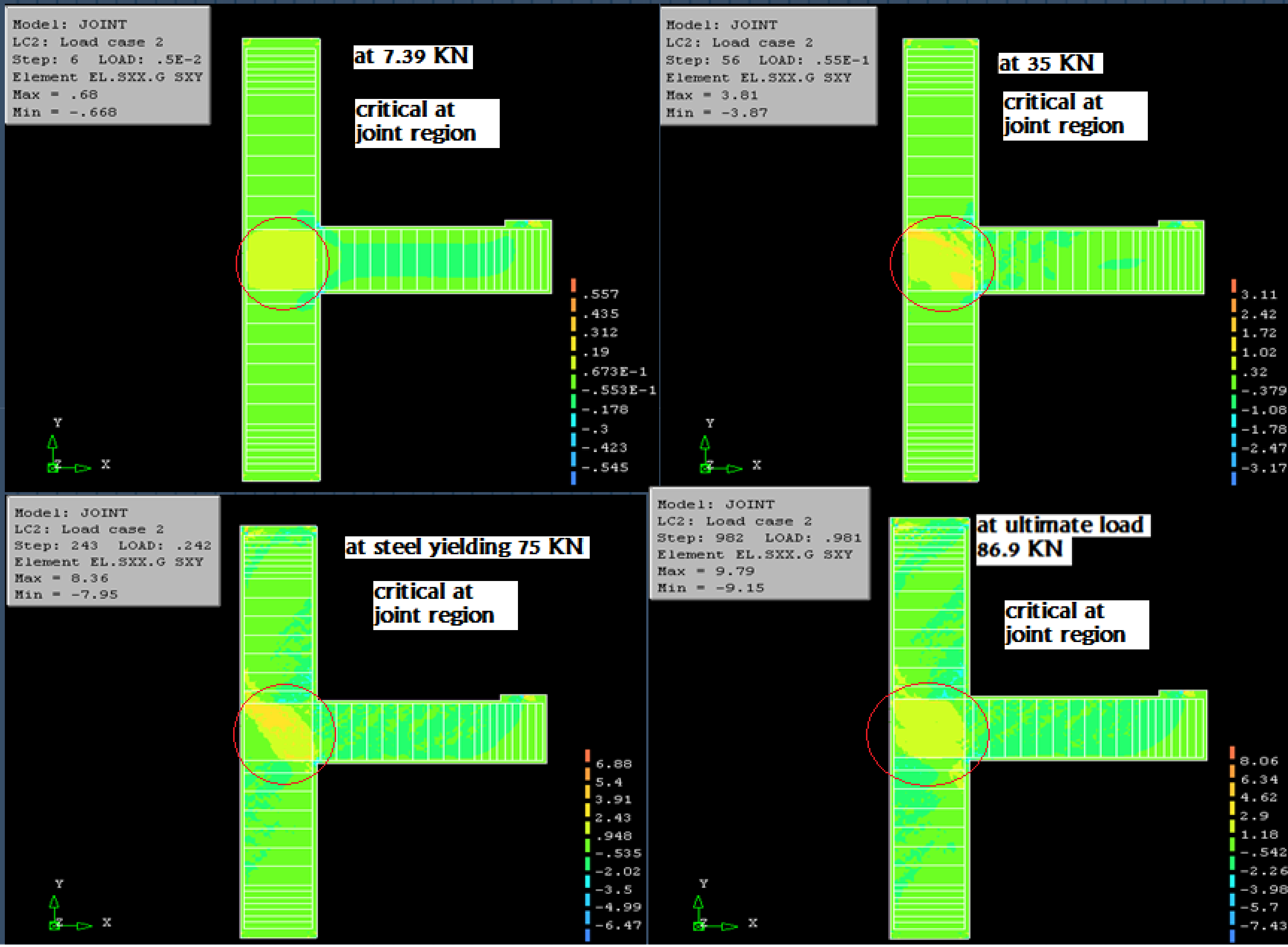
STRESS IN STEEL SXX (BEAM)



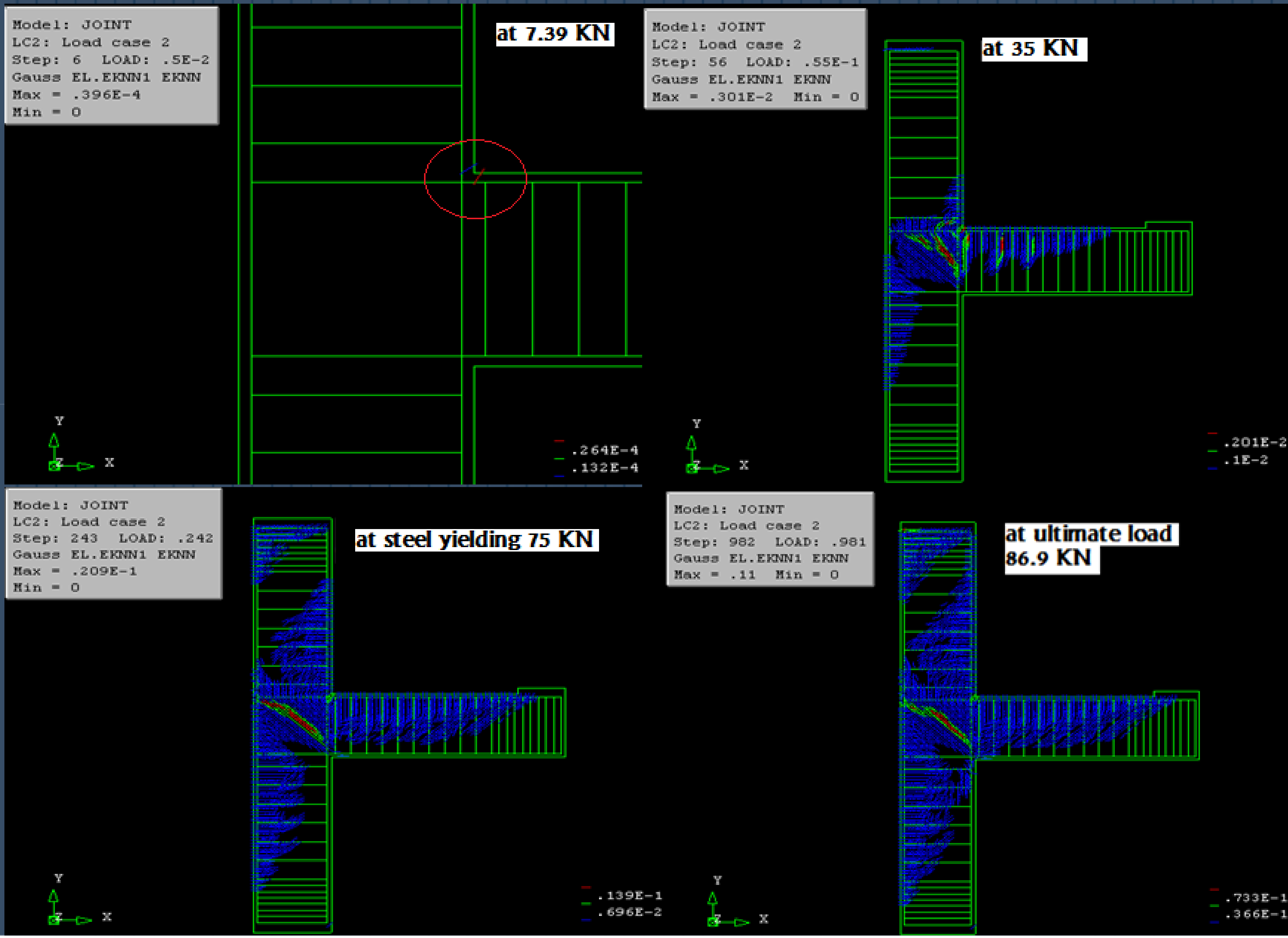
STRESSES IN CONCRETE SYY (COLUMN)



STRESSES IN CONCRETE SXY



CRACK PATTERNS



CONCLUSIONS

- The finite element simulation of the represented by the load-deflection shows good agreement with the test data which indicates that DIANA software with its 2-D plane stress model is able to capture the behavior of beam-column joint well.
- The crack patterns at various loads from the FE model correspond well with the experimentally observed failure modes, stresses in the beam, column and joints are in agreement.

WORK IN PROGRESS AT KFUPM

- In a collaborative program presently underway between Istanbul Technical university (ITU) and King Fahd University of Petroleum and Minerals (KFUPM) an experimental program is being conducted at KFUPM on the beam-column joints used in old reinforced concrete buildings in Saudi Arabia.
- Finite element simulation has been done for the static load test to capture the nonlinear behavior of the joint.

ACKNOWLEDGEMENT KFUPM

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