Dynamore GmbH - 2018 LS-Dyna Forum - Civil Engineering - 14 October 2018 – Raum 4- 16:00 hours

Finite Element Modeling of Long-Span Steel Suspension Bridges in Civil Engineering

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Outline

- Overview of the the Fatih Sultan Mehmet Bridge located in Istanbul, Turkey
- Finite element modeling
- Eigenvalue analysis results
- Earthquake simulations (recent progress)
- Conclusions

The Fatih Sultan Mehmet Bridge – a.k.a. The Second Bosporus Bridge

- Composed of steel towers and steel deck
- Span length: 1090m
- 2 x 4 lanes of traffic; commercial truck traffic (in the past) and now only local commuter traffic is allowed
- Total mass of 34,000 metric tons of steel
- Opened to service in July 1988 – built by a consortium of Japanese companies including the IHI Corporation and Mitsubishi Heavy Industries

BTITLE

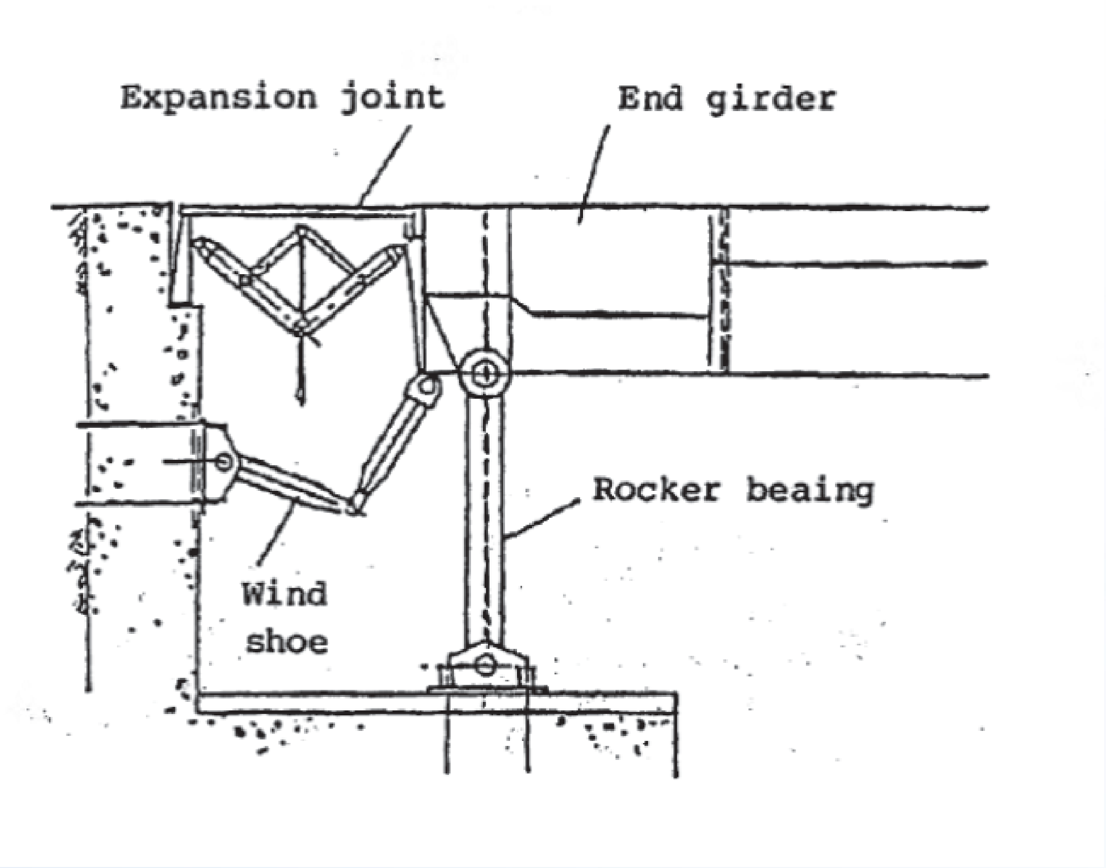
The Fatih Sultan Mehmet Bridge – a.k.a. The Second Bosporus Bridge

- Tower height above the road level: 98m
- Deck level above sea: 66m
- The 3m-high and 39.40m-wide bridge deck is a hollow steel box section composed of orthotropic stiffened panels
- Diaphragm wall panels exist in the deck structure approximately at every 4m.

The Fatih Sultan Mehmet Bridge

The Fatih Sultan Mehmet Bridge: Journey Back in Time (1987)

The Fatih Sultan Mehmet Bridge: Articulation; Rocker Bearing and Windshoe



The Fatih Sultan Mehmet Bridge: Articulation; Windshoe

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The Fatih Sultan Mehmet Bridge: Articulation; Rocker Bearing

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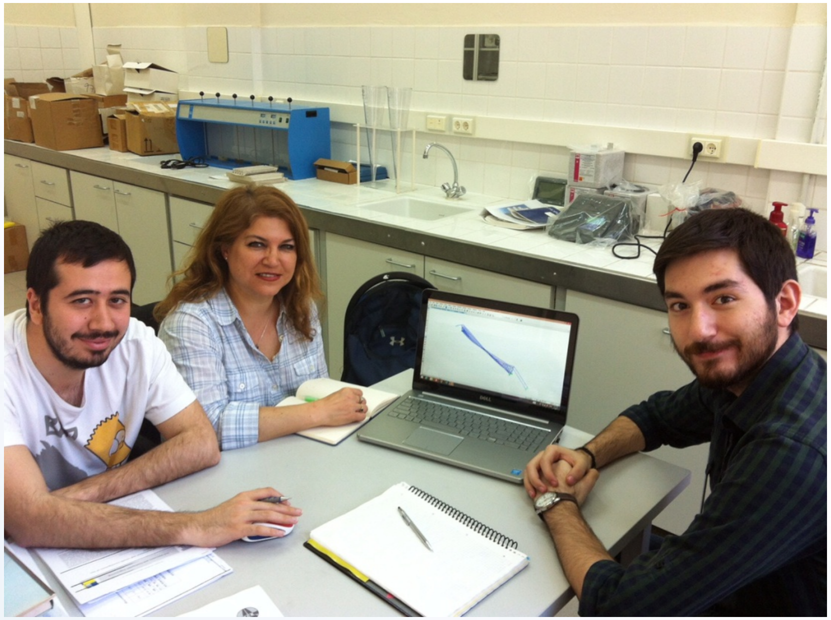
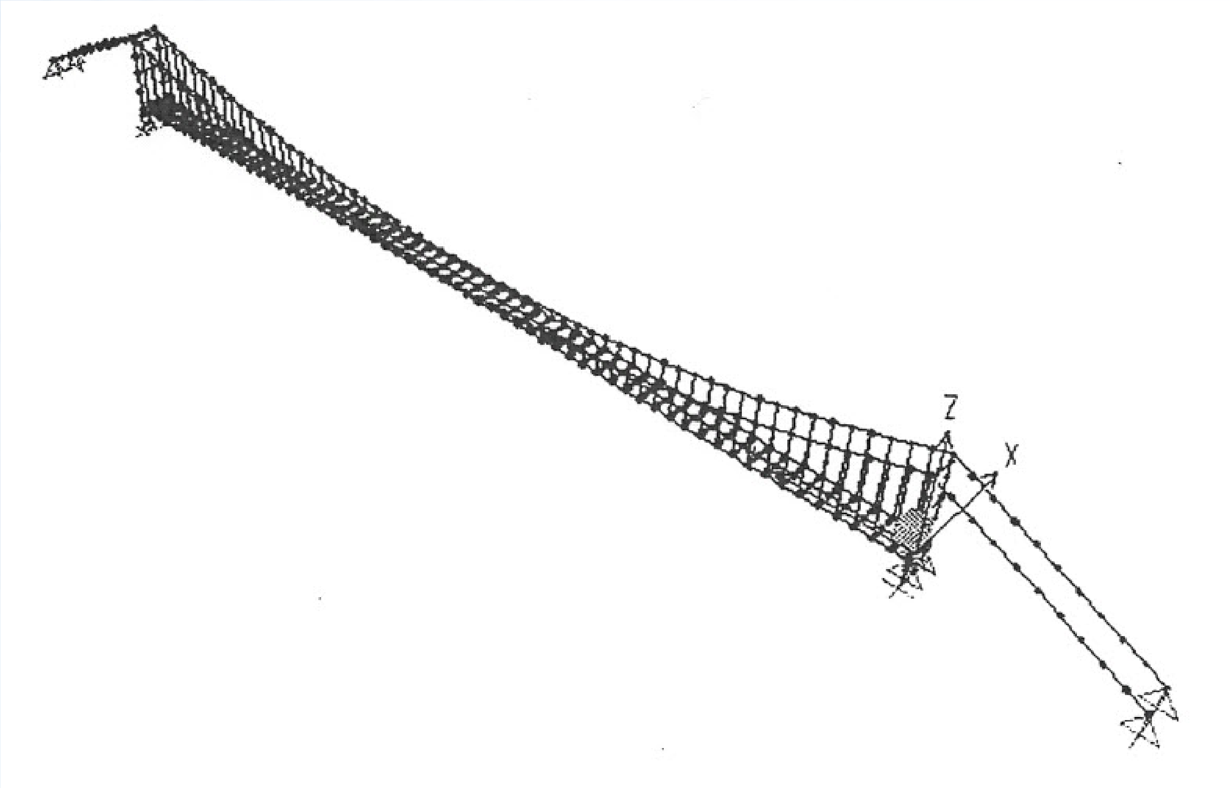
Line/Beam Element Models



- Advantages:
  - Easy to construct
  - Fast run-time
- Disadvantages:
  - Reasonable accuracy for global behavior
  - Poor accuracy for higher modes
  - Poor accuracy particularly for torsional modes
  - Not suited for modeling non-linear effects such as plastic strain concentration, impact between two entities coming into contact

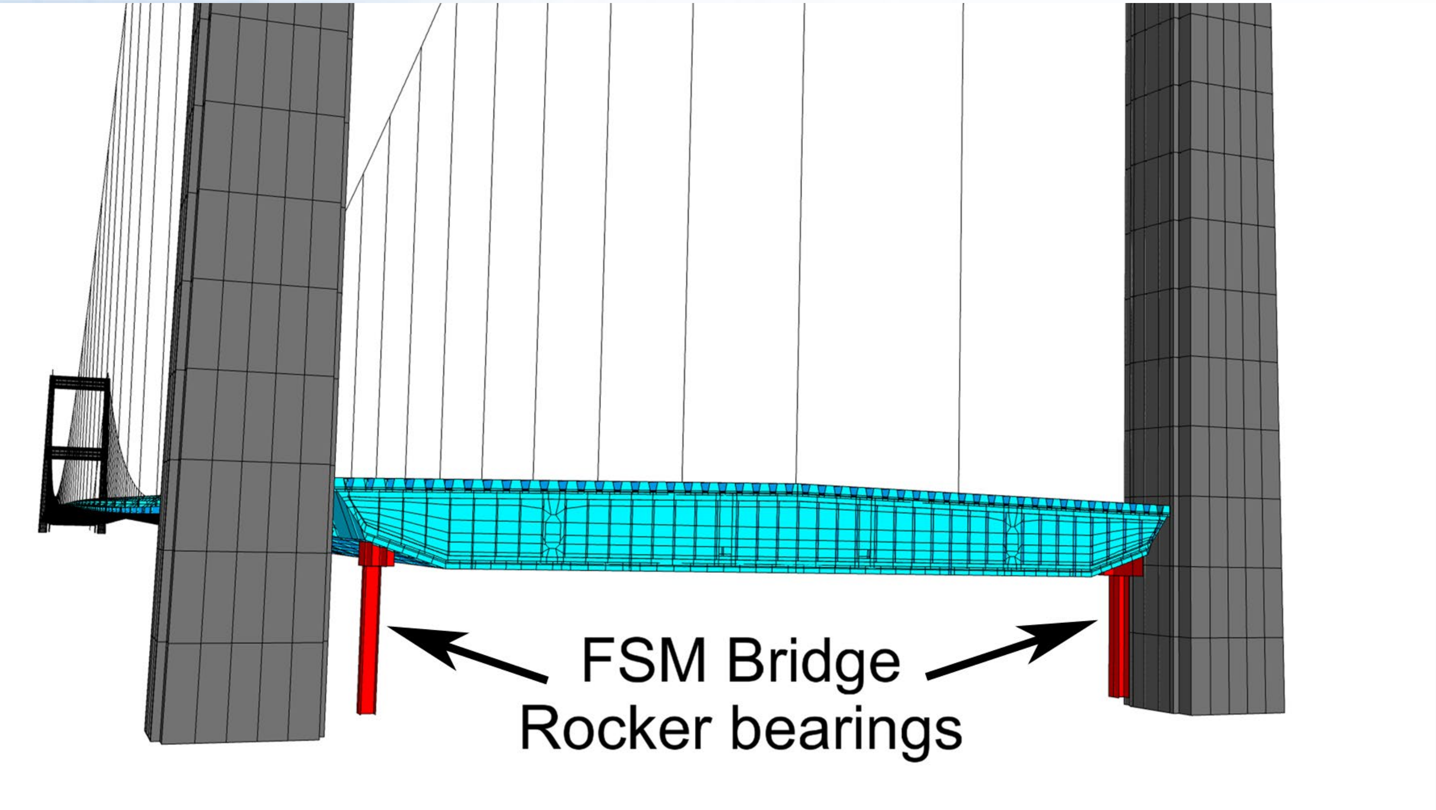
The Fatih Sultan Mehmet Bridge: Previous Work Done Using a Line Element Model



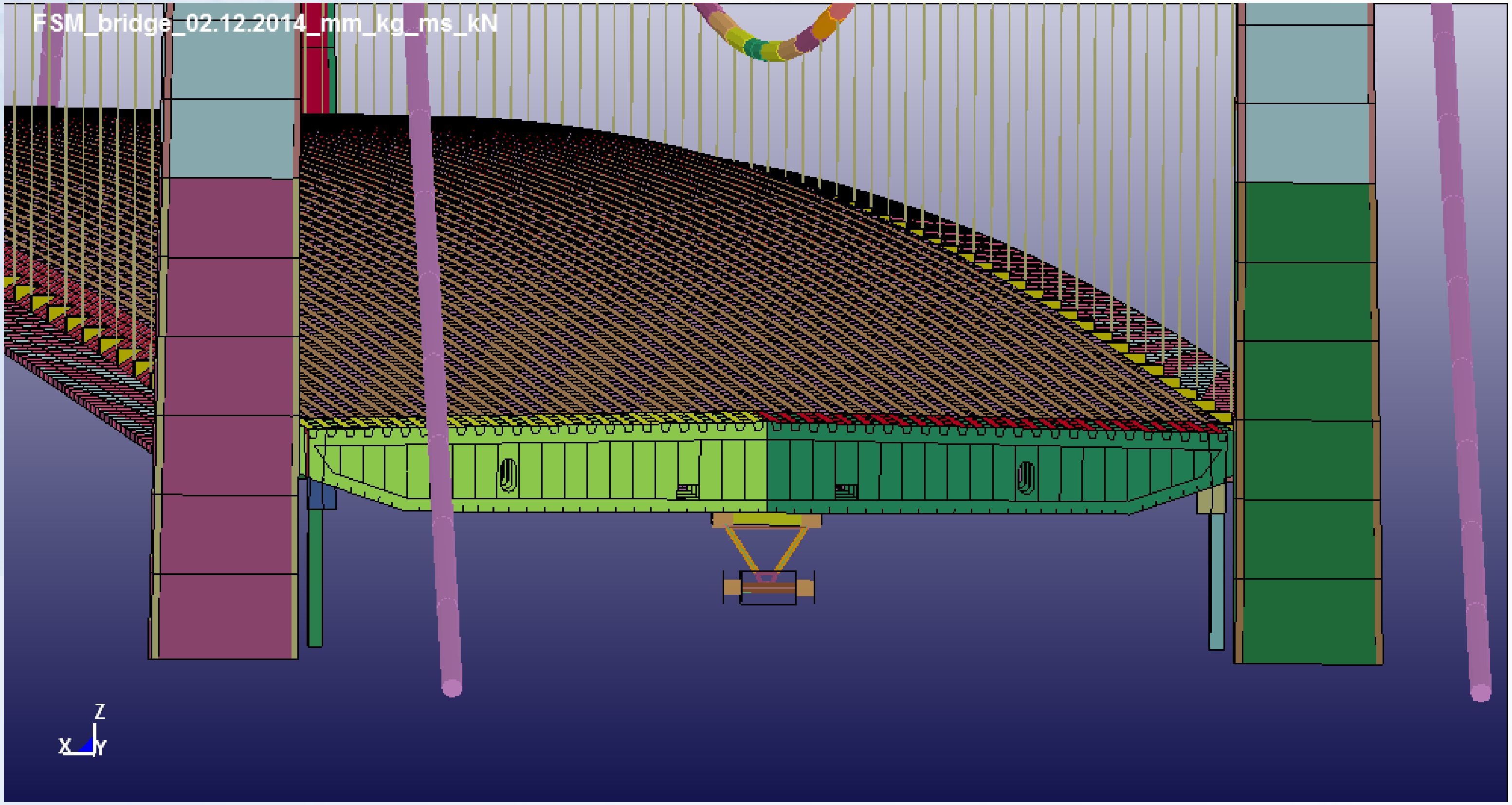
Shell Element Models

- Advantages:
  - Better accuracy; no need to fine-tune the model; no fudge factors; no adjustment knobs necessary
  - Suited for non-linear simulations
  - Better visualization
- Disadvantages:
  - Difficult to construct
  - Increased run-time for computations
  - Requires high performance parallel computing platforms for practical use

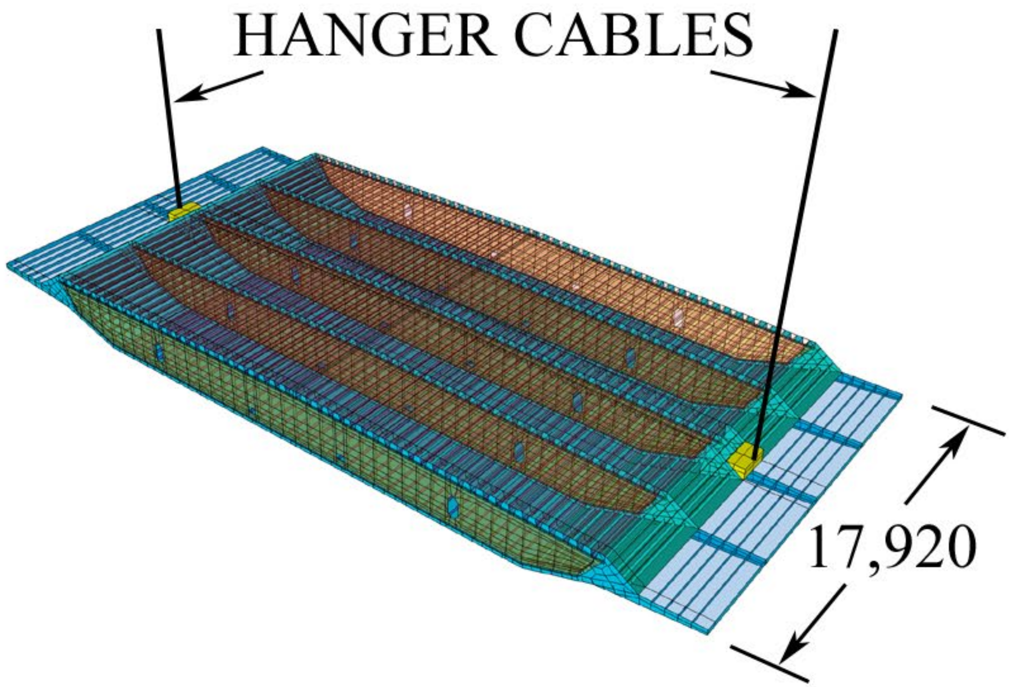
FSM: Shell Element Model (Continued)



FSM: Shell Element Model (Continued)



FSM: Shell Element Model (Continued)

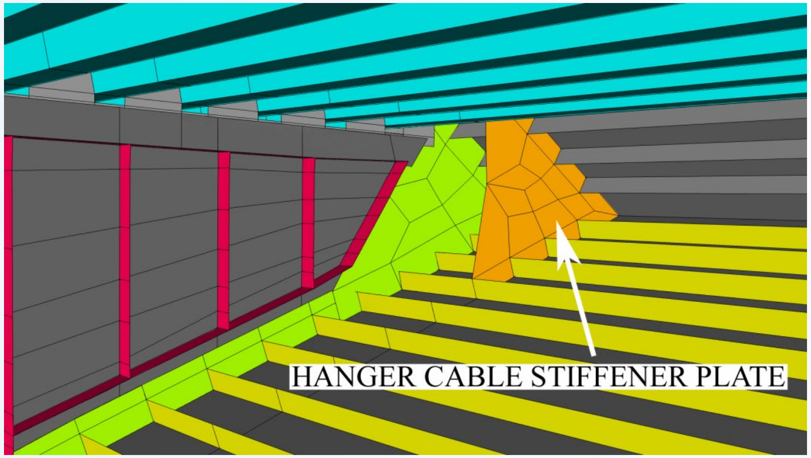


* The span dimension is given in millimeters.

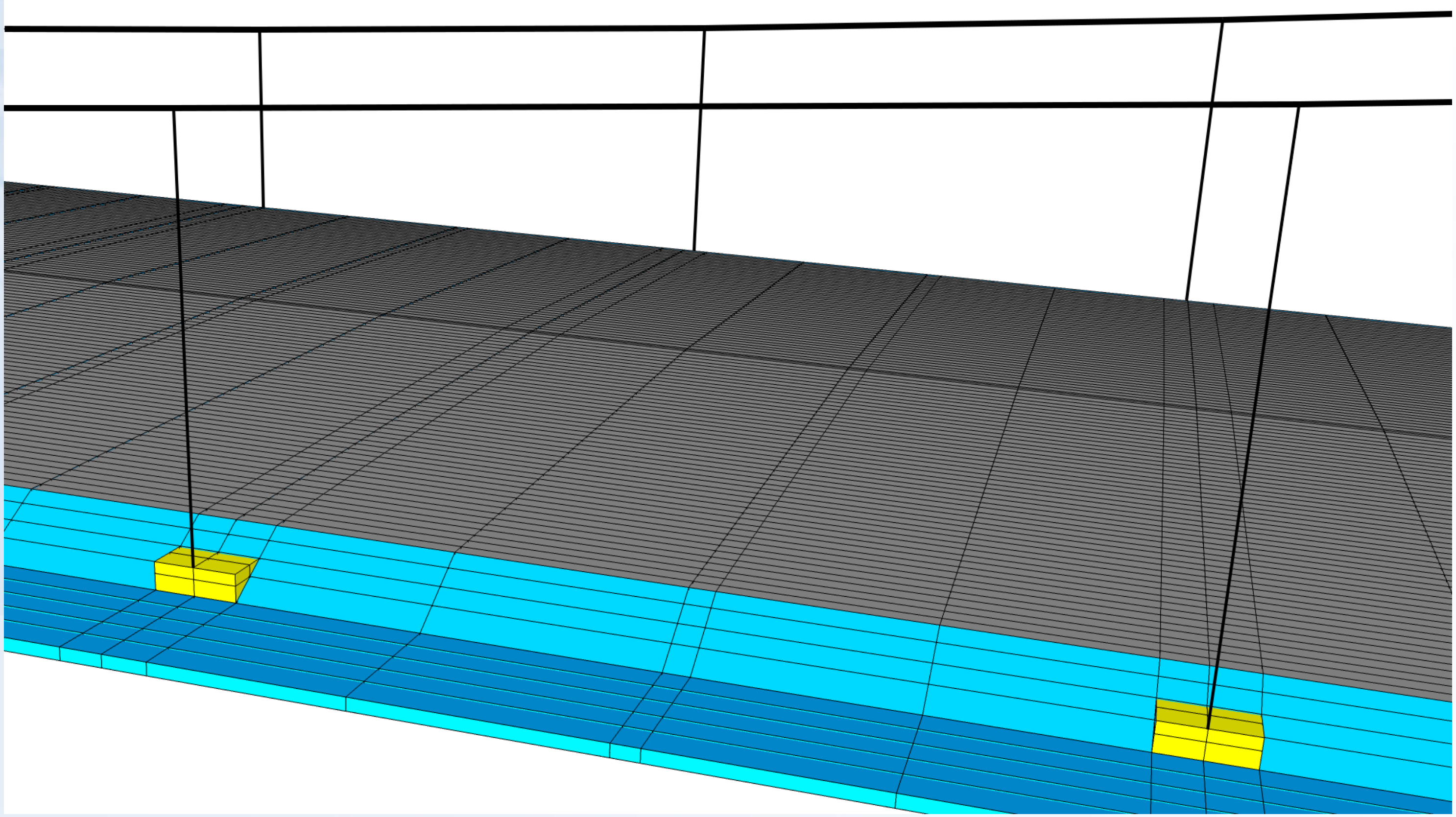
FSM: Shell Element Model (Continued)

Photo of the actual structure

LS-Dyna shell model



FSM: Shell Element Model (Continued)



FSM: Implicit Analysis Steps

The computations are done in a two-step scheme, i.e. in a first step the gravity load and cable pre-straining are applied simultaneously; the eigenmodes, modal masses and modal participation factors are calculated in the second step using the full restart capability of LS-DYNA. In this way the static pre-straining is separated from consecutive computations which allows for more flexibility during simulation runs.

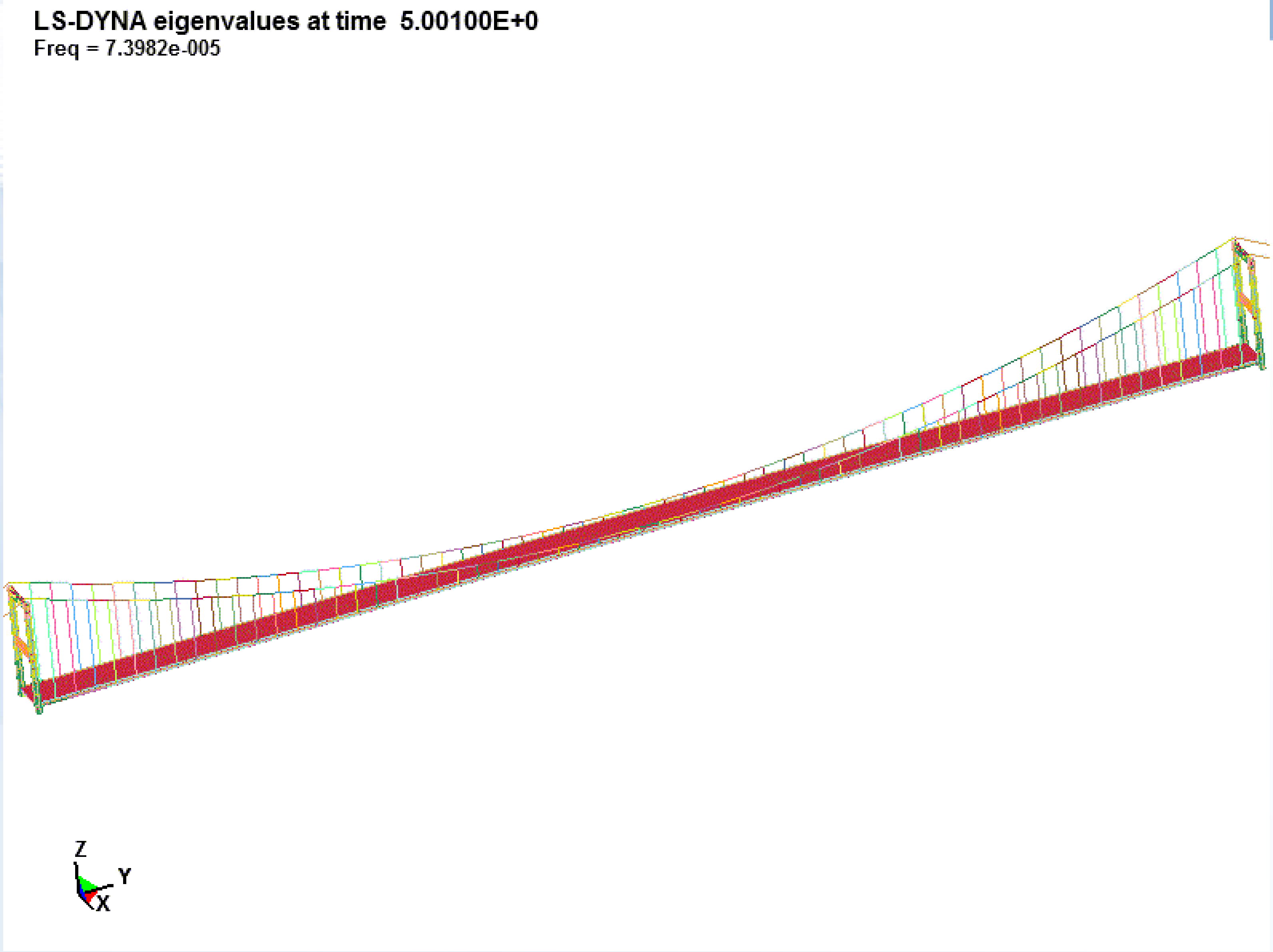
FSM: Implicit Analysis Steps

The non-linear static analysis of applying gravity load and cable pre-straining is achieved by means of LS-DYNA's full Newton solver, which is needed here since the default Broyden–Fletcher–Goldfarb–Shannon (BFGS) solver fails to obtain convergence. The gravity load and the pre-straining of the cables are applied in a synchronous way, i.e. both effects cancel each other and no displacements are observed; equilibrium is accomplished after four iterations. For the inherent matrix factorization the double precision direct sparse linear solver from the Boeing Extreme Mathematical Library (BCSLIB-EXT) is applied, which is a robust solver with sufficient numerical stability for such an intricate stiffness matrix where the dimensions vary over a range of several orders of magnitude. Utilizing one 12 core node of the Linux cluster JUDGE at Jülich Supercomputing Centre (JSC) SMP LS-DYNA needs 35 minutes for this non-linear static analysis.

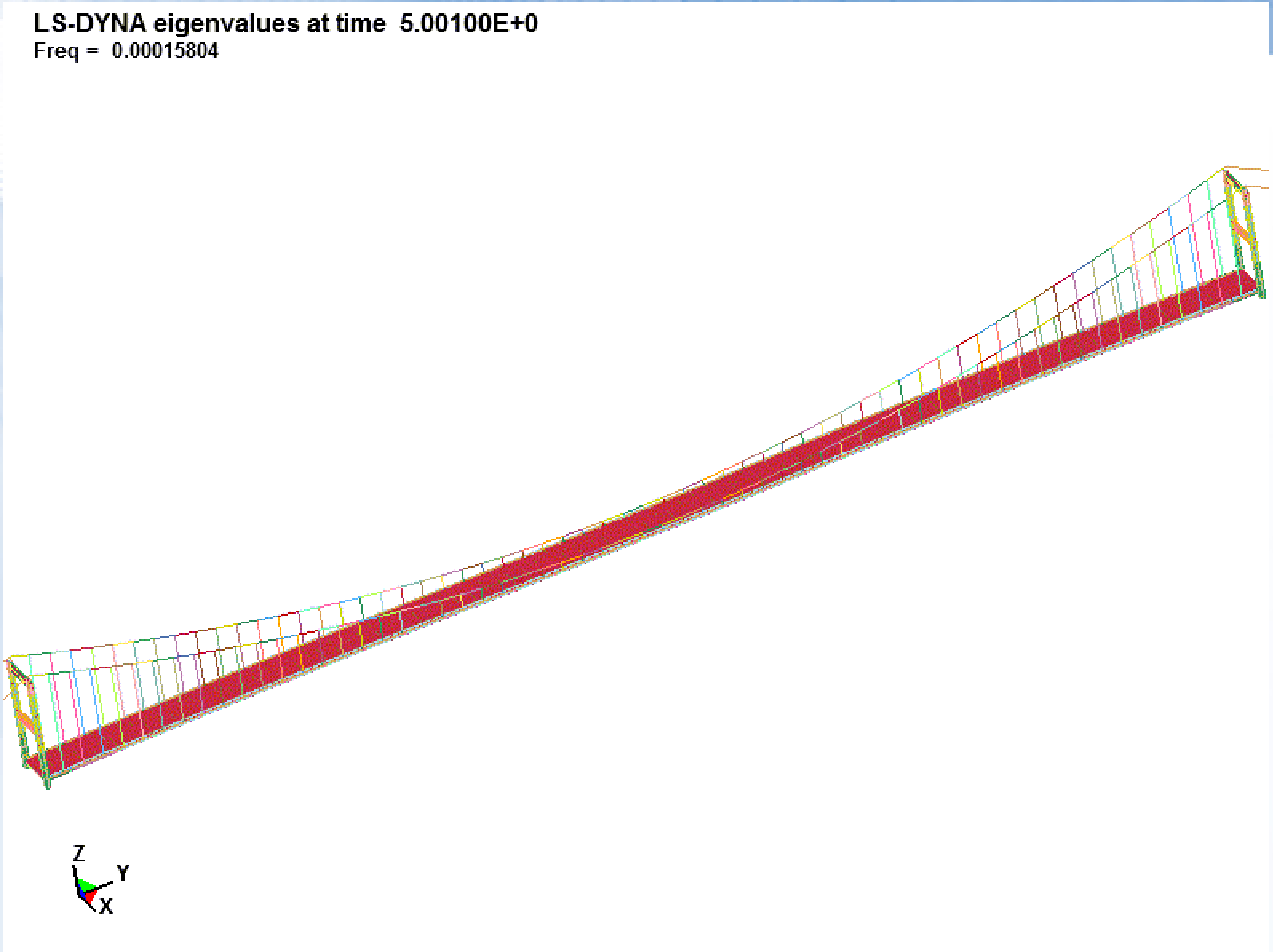
FSM: Implicit Analysis Steps

The solution of the eigenvalue problem is done by means of LS-DYNA's block shift and invert Lanczos eigensolver from BCSLIB-EXT. The computation of the first 40 eigenmodes is achieved by SMP LS-DYNA in 25 minutes using again one node with 12 cores. These first 40 eigenmodes are not sufficient to catch all important contributions to modal masses, i.e. the modal mass is well below 90% of the total physical mass for x-translational, y-translational and z-translational modes. In fact, one has to compute the first 1300 eigenmodes in order to meet the 90% accumulated modal mass demand. This computation takes almost 10 hours using 12 cores. Despite the computational effort, the dominant number of the calculated 1300 eigenmodes are pure cable modes, which are not of importance for the present study, but are inevitably calculated in the eigenvalue analysis.

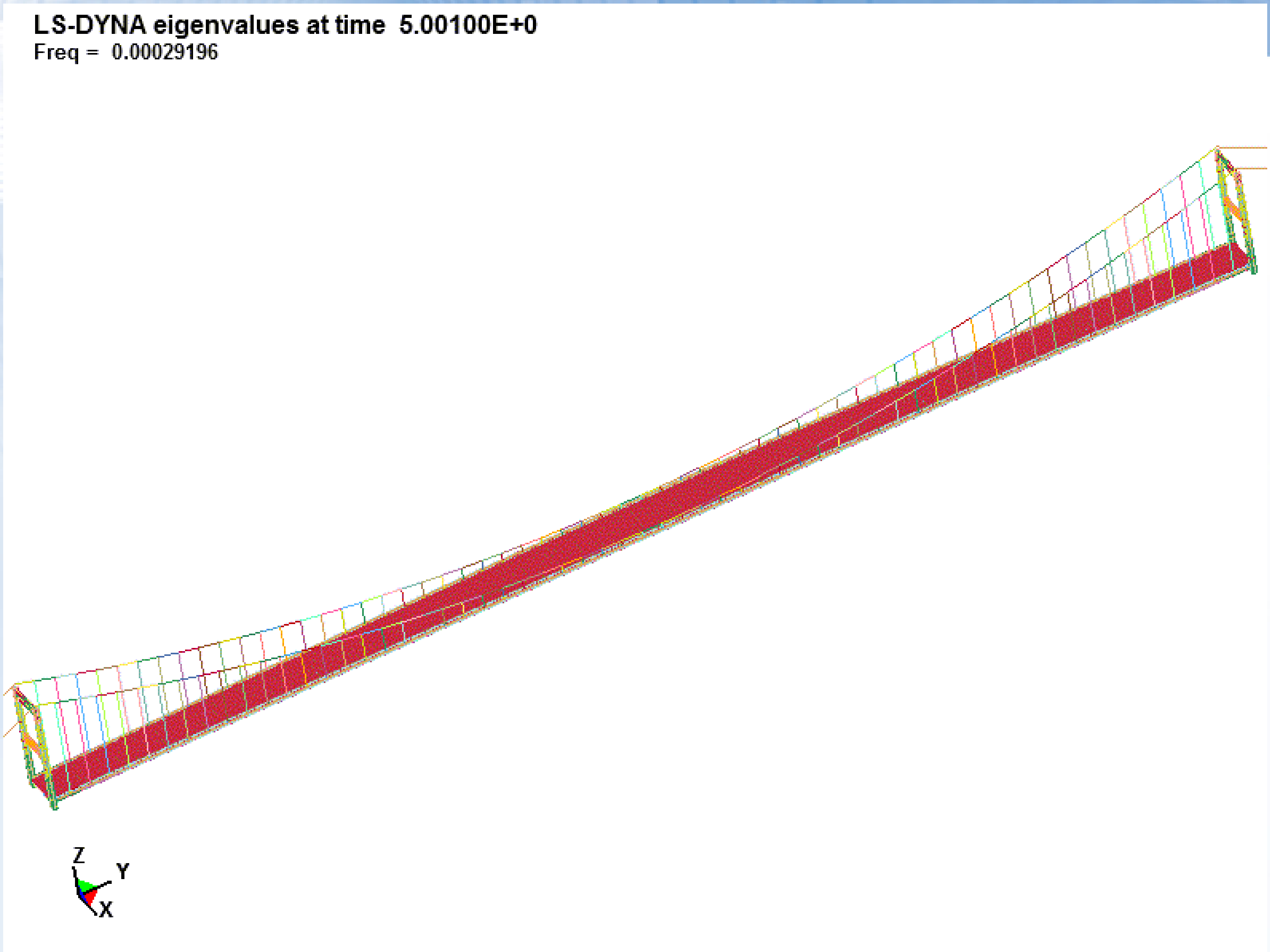
Eigenvalue Results: Lateral Mode



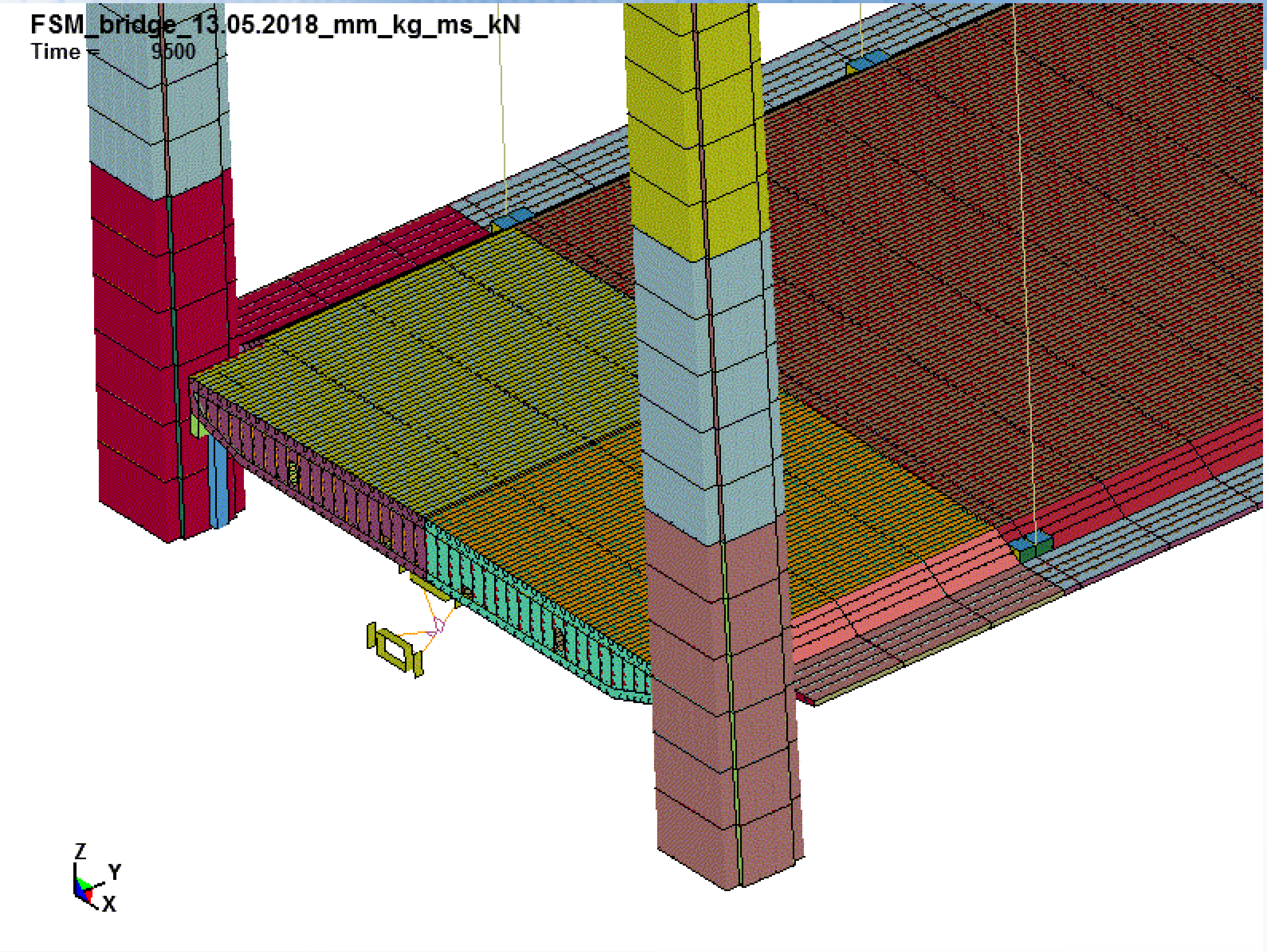
Eigenvalue Results: Vertical Mode



Eigenvalue Results: Torsional Mode

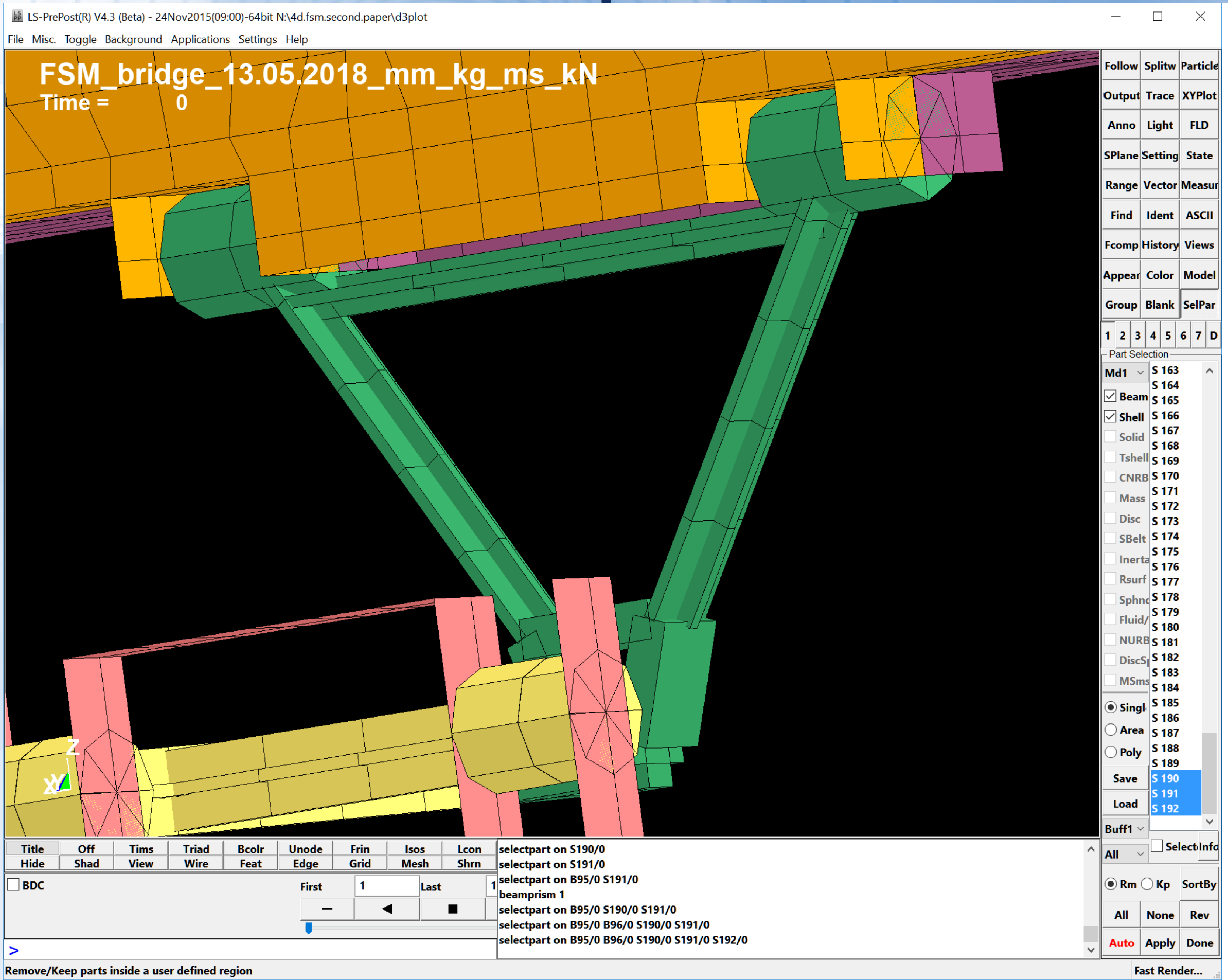


Erdbeben Results: Catwalk to Tower Impact

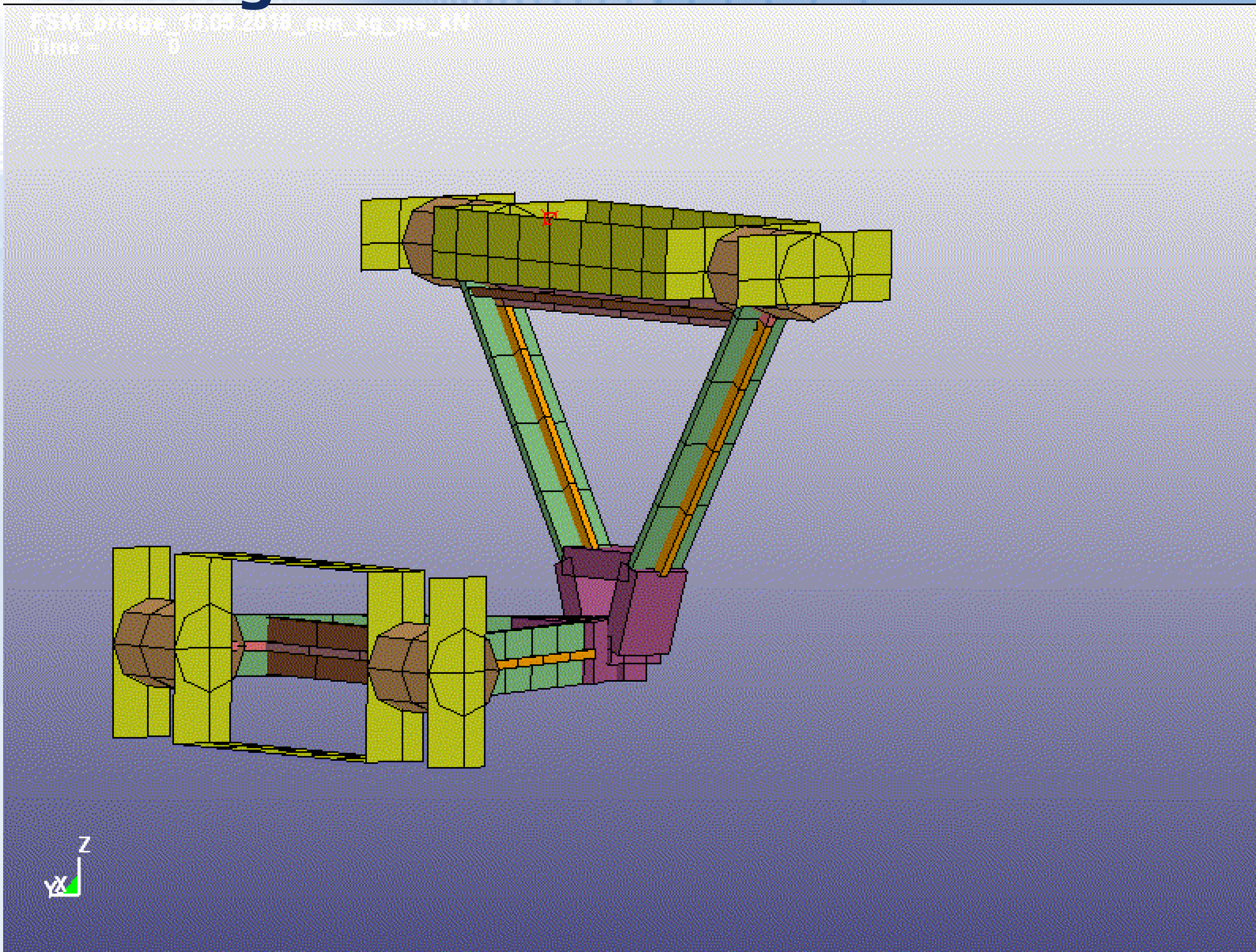


Earthquake/Erdbeben Simulations with Implicit-Explicit Switching

MPP Domain Decomp. Problem Constraints



MPP Domain Decomp. Error: Constraint is Defunct / Windshoe to Deck Connection is not working !

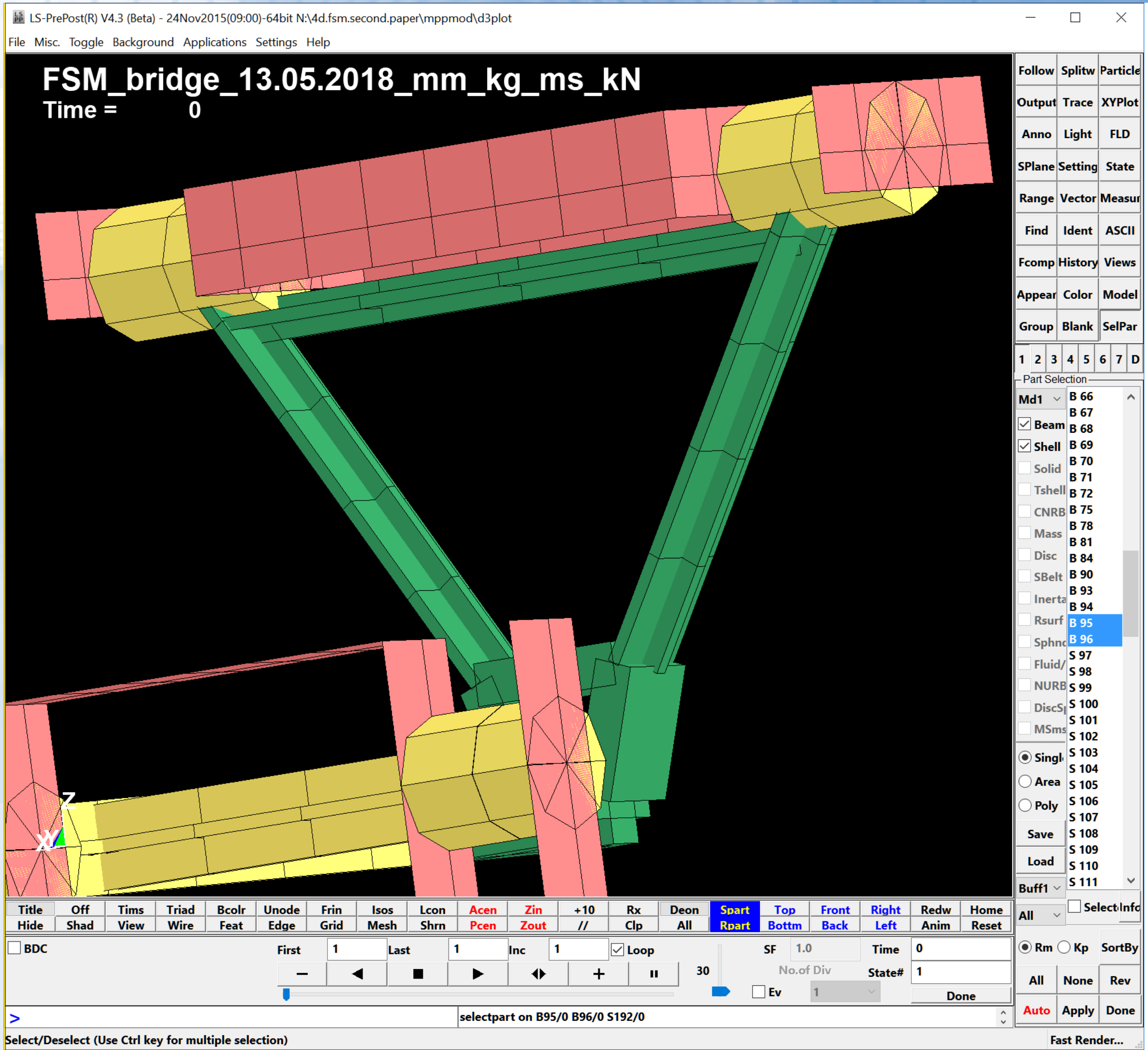


MPP Dom. Decomp.: How to Fix it Manually?

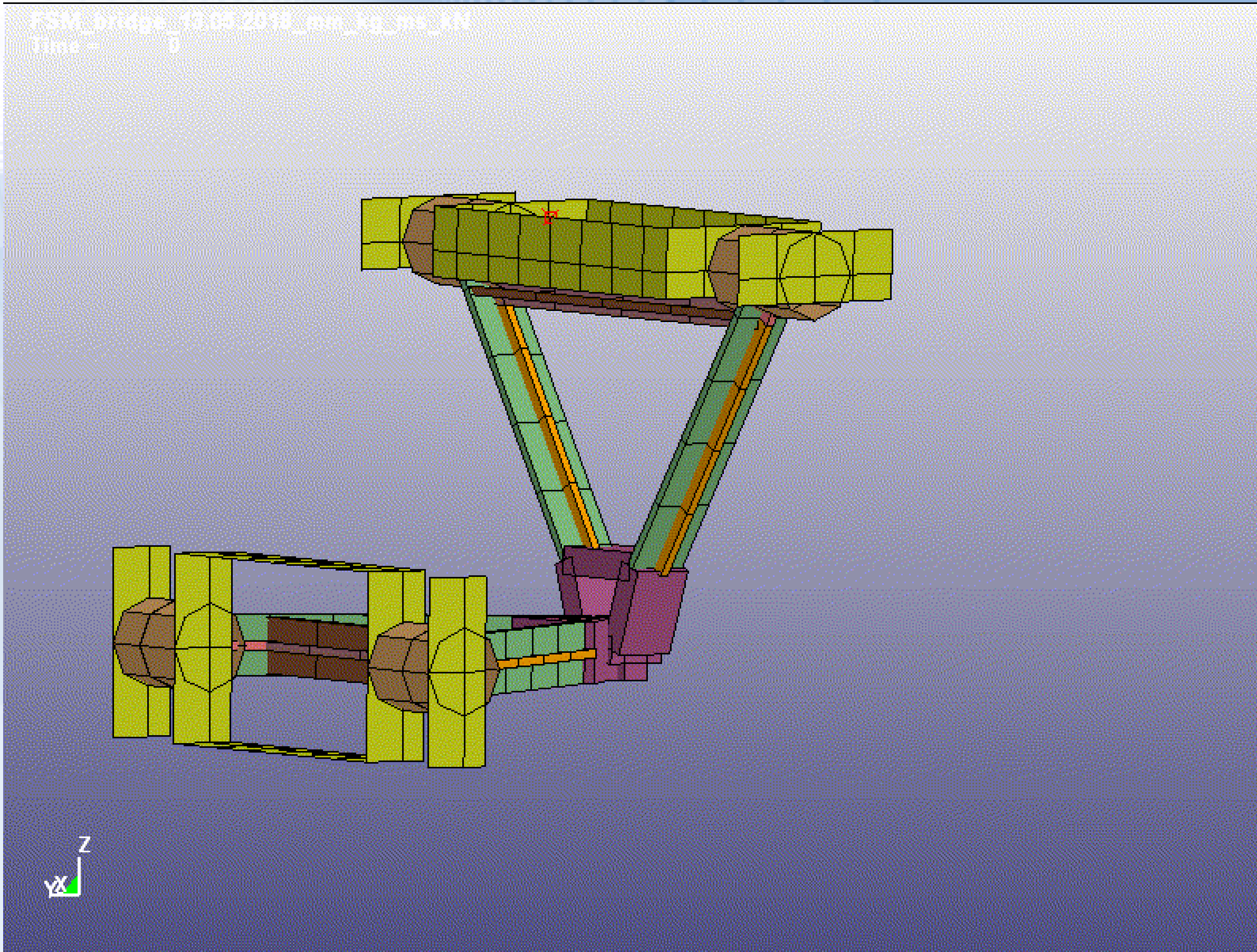
FSM_13.05.2018.k

```
$# LS-DYNA Keyword file created by LS-PrePost(R) V4.3.10 - 19Jun2017
$# Created on May-13-2018 (22:51:37)
*KEYWORD MEMORY=1950000000
*TITLE
$#                                                                         title
FSM_bridge_13.05.2018_mm_kg_ms_kN
$# *CONTROL_MPP_DECOMPOSITION_NUMPROC
$#         96
$# *CONTROL_MPP_DECOMPOSITION_SHOW
*CONTROL_MPP_DECOMPOSITION_OUTDECOMP
         1
*CONTROL_MPP_DECOMPOSITION_ARRANGE_PARTS
       100        11
*SET_PART_LIST
$#       sid       da1       da2       da3       da4    solver
       100       0.0       0.0       0.0       0.0MECH
$#      pid1      pid2
       101       102
*CONTROL_ENERGY
$#      hgen      rwen    slnten     rylen
         1         1         1         2
*CONTROL_IMPLICIT_GENERAL
$#    imflag       dt0    imform      nsbs       igs     cnstn      form    zero_v
        -2    2499.0         2         1         1         0         0         0
*CONTROL_IMPLICIT_SOLVER
$#    lsolvr    lprint
         4         3
$#    lcpack    mtxdmp
```

MPP Dom. Decomp. Problem Manually Fixed



MPP Domain Decomp. Correction for Constraints: Problem Fixed



Conclusions

- Shell model and ambient vibration measurements are in agreement for a wide range of eigenmodes, including the torsional model
- Earthquake/Erdbeben simulations demonstrate the possibility of deck-to-tower impact for strong ground motions.
- Future work will involve the investigation of large vibrations dampers that could be installed in the bridge. Currently, the larger-span Osmangazi Izmit Bay Crossing Bridge has vibrations dampers installed, and the bridge is currently in service.

Further Information

- **Refereed paper in an archival journal:**

Kilic, S. A., Raatschen, H. J. , Körfgen, B., Apaydin, N. M., Astaneh-Asl, A., "FE Model of the Fatih Sultan Mehmet Suspension Bridge Using Thin Shell Finite Elements", Ara. Jou. Sci. Eng., Springer, 42(3), 1103-1116, March 2017.

Thank you for your attention!

Questions?