

**Appendix to report:**

SBJ-33-C5-OON-22-RE-015-B  
K12 - SHIP IMPACT, BRIDGE GIRDER

**Appendix title:**

APPENDIX A – ABAQUS TERMINOLOGY

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CONCEPT DEVELOPMENT FLOATING BRIDGE E39 BJØRNAFJORDEN



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The K12 - Ship impact, Bridge girder report [1] aims to describe the analyses performed as accurately as possible. This necessitates some terminology specific to Abaqus [2], the FEM analysis software used in this report. Emphasis is on concepts that are specific to Abaqus or terminology that differs from the standard.

# 1 AXES AND DEGREES OF FREEDOM

Abaqus numbers its axes 1, 2 and 3. For rectangular coordinate systems (mostly used in this analysis), this corresponds to axes x, y and z. The coordinate system can be global (same as in the global analysis, x axis roughly in the same direction as the girder) or local (used for ship-pontoon and ship-girder connection).

Abaqus labels its translational degrees of freedom U1 (displacement in axis 1), U2 (displacement in axis 2) and U3 (displacement in axis 3). Connecting the translational degrees of freedom of two nodes requires transferring concentrated forces. Rotational degrees of freedom are UR1 (rotation about axis 1), UR2 (rotation about axis 2) and UR3 (rotation about axis 3).

## 2 ENERGY MEASUREMENTS

Abaqus provides several energy-related timeseries. These have different acronyms. These measurements are generally over the whole model but may also be recorded for a specific set (specifically noted).

- **ALLKE** [Joule]: Kinetic energy in model integrated over all nodes as a function of time
- **ALLSE** [Joule]: Strain energy in model integrated over all nodes as a function of time
- **ALLVD** [Joule]: Cumulative viscous dissipation in model. Normally monotonically increasing.
- **ALLPD** [Joule]: Cumulative plastic dissipation in model. Normally monotonically increasing.
- **ALLAE** [Joule]: Artificial strain energy. Related to hourglass control and drilling rotation control.
- **ALLWK** [Joule]: Work of the external forces.
- **ALLIE** [Joule]: Total strain energy in model. For the simulations in this report:  
 $ALLIE = ALLSE + ALLPD + ALLAE$
- **ETOTAL** [Joule]: Energy balance. For the simulations in this report:  
 $ETOTAL = ALLKE + ALLIE + ALLFD + ALLVD - ALLWK$

## 3 ANALYSIS PROCEDURES

Abaqus provides two different procedures for dynamic analyses:

- **Implicit** analyses require dynamic equilibrium in a future time step. This means that changes in displacement and speed for the degrees of freedom depend on future displacement and speed, producing an implicit system of equations, and equation system solution is required.
- **Explicit** analyses require dynamic equilibrium in current and past time steps. Changes in displacement and speed for the degrees of freedom thus only depend on current displacement and speed. We obtain an explicit system of equations that may be solved by regular substitution.

Parameter for the implicit analyses in this report are chosen so that the solution procedure is *unconditionally stable*. This means numeric conservation of energy and momentum. In contrast, explicit analyses are only *conditionally stable*, and generally require very small time increments. CPU time required for solving each time increment, however, is much smaller. This has some general effects on suitability for each solution procedure.

### Implicit analyses:

- Can be run interchangeably with static analyses
- Are suited for analyses over a long time frame
- Require smooth nonlinearities

### Explicit analyses:

- Cannot be run interchangeably with static analyses
- Are suited for short analyses with detailed time resolution
- Can handle non-smooth nonlinearities

A general rule of thumb is to stick to implicit analyses and bring out Explicit analyses in case of convergence trouble, typically with analyses related to impact, fracture and contact. Impact modeling with use of contact properties in the analysis typically results in non-smooth nonlinearities, which may require explicit analysis. In our case, careful interaction modeling with connectors and smooth force-displacement curves produces a relatively smooth model that the implicit procedure can handle.

## 4 REFERENCES

- [1] SBJ-33-C5-OON-22-RE-015-B, "Concept developement floating bridge E39 Bjørnafjorden - K12 - Ship impact, Bridge girder," Norconsult, Dr. Techn. Olav Olsen, 2019.
- [2] Simulia, "Abaqus/CAE 2017," Dassault Systèmes, 2016.