LS-DYNA features:

Staged Construction

*CONTROL_STAGED_CONSTRUCTION etc

This presentation is a basic introduction to Staged Construction in LS-DYNA. See also the Remarks for *CONTROL_STAGED_CONSTRUCTION in the Keyword Manual.

LSTC Livermore Software Technology Corp.

ARUP

Staged construction: what is it?

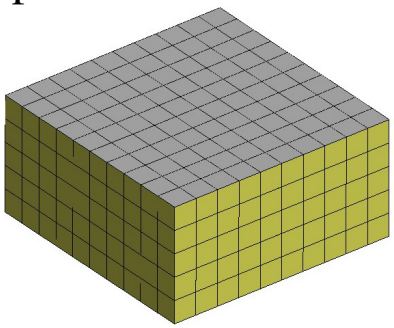
- Break the analysis into periods of time that can be referenced in loading definitions and rerun separately
- Introduce parts sequentially during the analysis, including self-weight, e.g. new construction
- Remove parts at particular times during the analysis, e.g. excavating soil, removing temporary props
- With the explicit analysis method, we use time scaling to reduce the analysis time to the order of 10-100 seconds, i.e. there is a scaling factor between real-life time and analysis time.
- With the short analysis time comes a risk of introducing unrealistic dynamic effects. These are reduced by:
  - Applying and removing loads gradually (ramp, not step)
  - Applying damping (e.g. *DAMPING_GLOBAL)

Staged construction analysis: why?

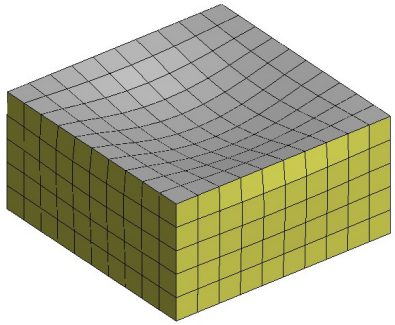
- Set up correct initial condition for main analysis
  - E.g. prepare model for a seismic analysis
  - In-situ stresses/deformation may be dependent on construction sequence
  - Set up correct stresses in load-bearing versus non-loadbearing walls
  - Retro-fit materials should not be stressed by the weight of the structure
- Analyse conditions during construction
  - Examine risk of failures when structure is incomplete
  - Soil heave/settlement in response to excavation and new construction

Example: non-loadbearing walls

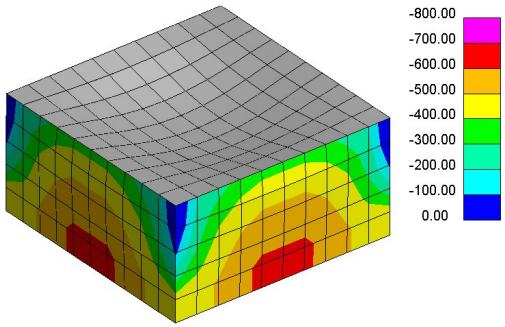
Complete structure present at time=0



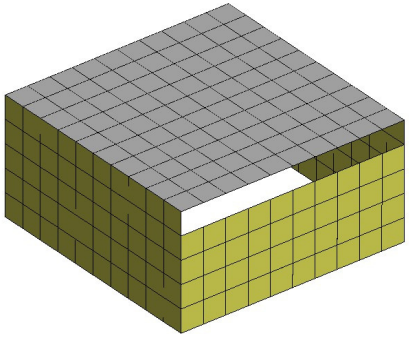
Add gravity



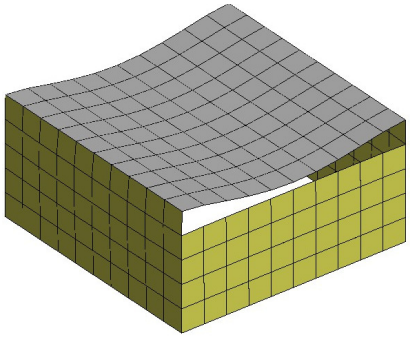
2-way spanning slab; all walls equally loaded



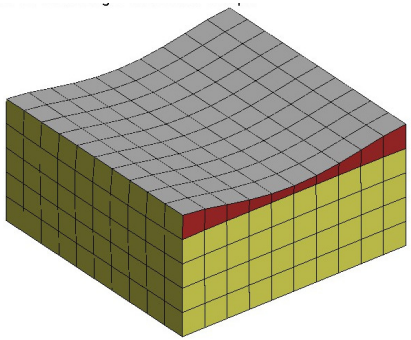
Incomplete structure present at time=0



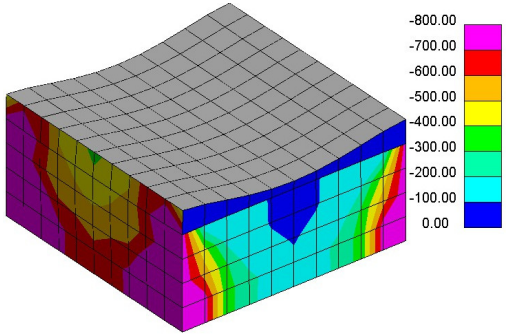
Add gravity



Fill gap

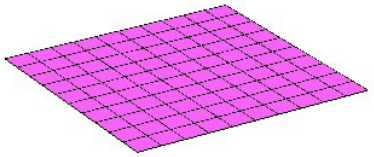


1-way spanning slab; walls differentially loaded

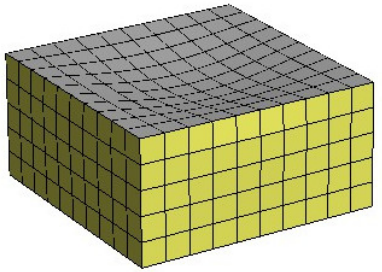


Example

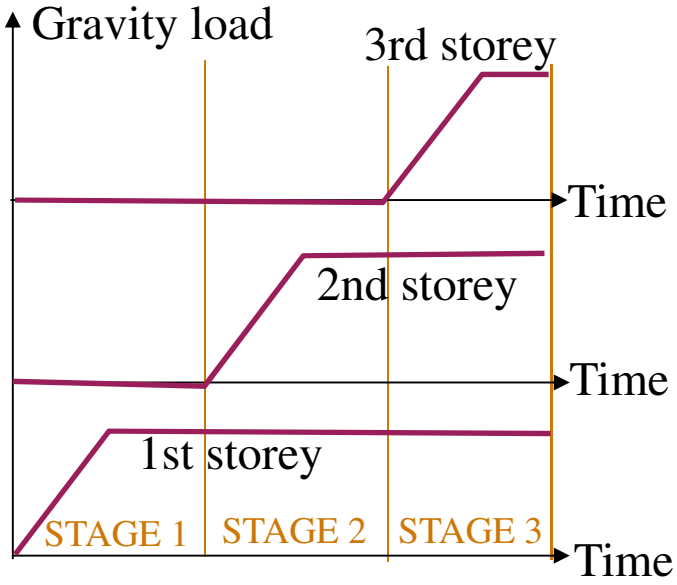
- Parts added sequentially
- As each part is added, its self-weight is automatically ramped up from zero to its full value

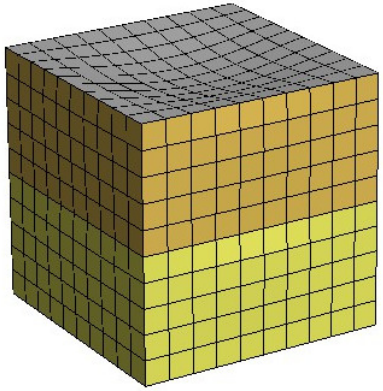


Start of analysis

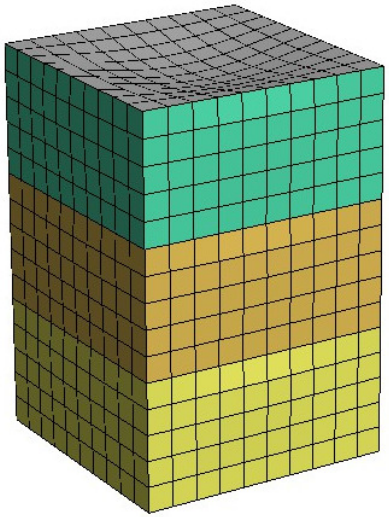


End of Stage 1





End of Stage 2



End of Stage 3

Staged Construction Keywords

Main keywords:

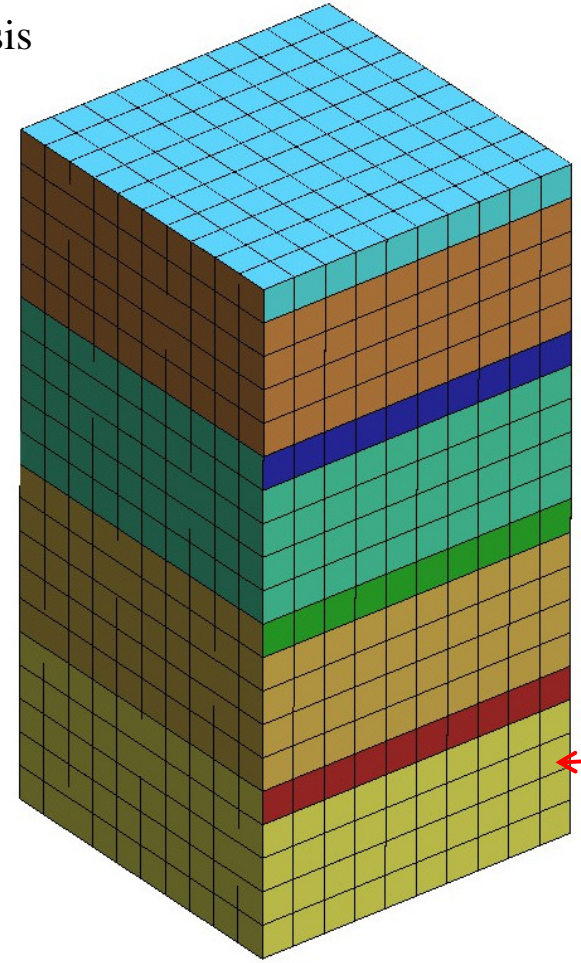
- *CONTROL_STAGED_CONSTRUCTION
  - Which stages should be run; gravity acceleration to be applied
- *DEFINE_CONSTRUCTION_STAGES
  - Define the start and end times of each stage
- *DEFINE_STAGED_CONSTRUCTION_PART (_SET)
  - Define the stages at which parts become active or are removed

Subsidary keywords (not usually defined in the keyword file, but LS-DYNA creates them automatically in response to the above):

- *LOAD_STIFFEN_PART
- *LOAD_REMOVE_PART
- *LOAD_GRAVITY_PART

Example: keywords

Initial model contains all the elements, including parts that become active later in the analysis



```
*CONTROL_STAGED_CONSTRUCTION
$         STAGE_START STAGE_END    GRAVITY    DORMANT
       0.0           5          12       10.0    1.0E-9
.

*DEFINE_CONSTRUCTION_STAGES
$    STAGE    T_START      T_END    T_RAMP
         1        0.0        1.0       0.5
         2        1.0        2.0       0.5
         3        2.0        3.0       0.5
         4        3.0        4.0       0.5
         5        4.0        5.0       0.5
         6        5.0        6.0       0.5
         7        6.0        7.0       0.5

*DEFINE_STAGED_CONSTRUCTION_PART
$       PID       STGA       STGR
         5          0          0
         6          5          0
         7          5          0
         8          7          0
         9          7          0
        10          0          0
```

Example: Part ID 6 becomes active at Stage 5, starting at analysis time 4.0, and the gravity load will be ramped up over the next 0.5 seconds.

Adding/deleting elements, and application of gravity loading, is managed automatically by LS-DYNA

Notes

The analysis does not have to begin at Stage 1. In this case, the analysis begins at Stage 5 so the analysis time will begin at 4.0 (not at 0.0).

The first stage MUST begin at Time = 0.

Acceleration due to gravity is defined here. Gravity will be applied to all parts defined under *DEFINE_STAGED_CONSTRUCTION_PART. Do NOT use *LOAD_BODY in addition to staged construction.

```
*CONTROL_STAGED_CONSTRUCTION
$        STAGE_START STAGE_END    GRAVITY    DORMANT
       0.0           5          12         10.0     1.0E-9
.
```

```
*DEFINE_CONSTRUCTION_STAGES
$    STAGE    T_START      T_END    T_RAMP
         1        0.0        1.0       0.5
         2        1.0        2.0       0.5
         3        2.0        3.0       0.5
         4        3.0        4.0       0.5
         5        4.0        5.0       0.5
         6        5.0        6.0       0.5
         7        6.0        7.0       0.5
```

This is how to define a part that is present throughout the analysis, and receives gravity load from *CONTROL_STAGED_CONSTRUCTION.

Parts omitted from this list will be present throughout the analysis, but will not receive gravity loading from *CONTROL_STAGED_CONSTRUCTION.

```
*DEFINE_STAGED_CONSTRUCTION_PART
$       PID       STGA       STGB
         5          0          0
         6          5          0
         7          5          0
         8          7          0
         9          7          0
        10          0          0
```

Active, Dormant, and Removed Parts

- "Active" is the normal condition for elements in an LS-DYNA analysis.
- "Dormant" is a state specific to Staged Construction and occurs before the analysis reaches the stage where the part becomes active (STGA on *DEFINE_STAGED_CONSTRUCTION_PART).
  - The elements are present in the analysis and are processed by LS-DYNA in the normal way, but any stresses or forces generated are scaled by the factor given on *CONTROL_STAGED_CONSTRUCTION – 1.0e-6 by default.
  - In the d3plot file, dormant elements are flagged as "deleted" so that post-processors automatically blank them out.
  - When they become active, the stress and history variables are re-initialized.
- Parts are removed when the analysis reaches the stage STGR on *DEFINE_STAGED_CONSTRUCTION_PART. These elements are deleted from the analysis and are no longer processed by LS-DYNA.
  - To reduce any dynamic response, gravity load is automatically ramped down to zero before the elements are deleted

Different behaviour in LS-DYNA R11 versus R10

- When a Part becomes active, the behaviour is different in R11 onwards compared to R10 and previous.
- In R11 onwards, the stiffness and strength jump immediately to their full values.
- In R10 and previous, the stiffness and strength were ramped up from zero in the same way as the gravity loading.
  - Disadvantage: unrealistic deformations can occur while the part is still soft/weak.
- In all versions, the gravity load ramps up as described in other slides.
- In all versions, the stiffness and strength are ramped down before removal of the Part (due to STGR on *DEFINE_STAGED_CONSTRUCTION_PART)
- If desired, the R11 behaviour can be obtained in previous versions by the methods described on the next slide.

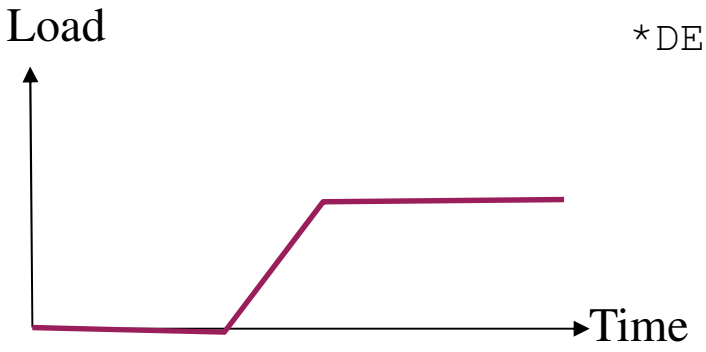
Overriding the default behaviour

The behaviour of *DEFINE_STAGED_CONSTRUCTION_PART described in previous slides can be overridden if desired:

- The variation of stiffness and strength versus time can be overridden using *LOAD_STIFFEN_PART with a loadcuvre
  - e.g. to make a Part reach its full stiffness and strength more quickly than the ramp time defined on *DEFINE_STAGED_CONSTRUCTION_PART.
- The variation of gravity load with time can be overridden using *LOAD_GRAVITY_PART with a loadcurve
  - e.g. to ramp up the gravity load slower than the ramp time defined on *DEFINE_STAGED_CONSTRUCTION_PART.
  - e.g. to apply less or more than the default amount of gravity loading.

Applying other types of loading

- Gravity load is applied automatically as described in previous slides
- Other loading (e.g. *LOAD_NODE, *LOAD_SEGMENT_SET etc) can be defined in the keyword file in the normal way.
  - It is recommended to use *DEFINE_CURVE to ramp up the loading, e.g.:




```
*DEFINE_CURVE
       100
               0.0                     0.0
               1.0                     0.0
               1.5                     1.0
             100.0                     1.0
```

Initial stress: beginning of first Stage

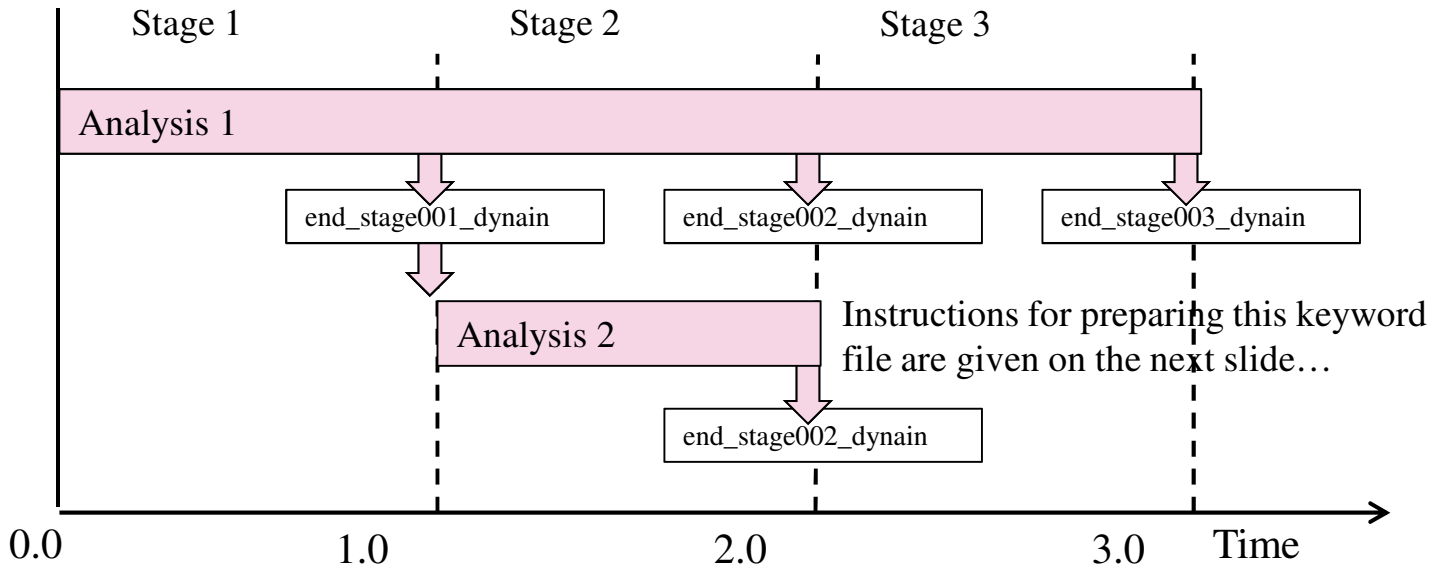
- To minimise dynamic effects, it is recommended to set an initial stress state in equilibrium with the initial loading.
- For parts that experience loading that ramps up from zero, no initial stress is required because the initial loading is zero.
- For parts that are active and receiving full gravity loading at the start of the first stage (STGA=0 on *DEFINE_STAGED_CONSTRUCTION_PART), it is desirable to define initial stresses balancing the gravity load, for example using *INITIAL_STRESS_DEPTH. This method is recommended for soil.

Timestep control (explicit analysis method)

- Active elements have the usual influence on timestep and/or mass-scaling.
- Dormant elements are treated as having their usual mass, but reduced stiffness; hence the timestep calculated for these elements is much larger than if the same elements were active.
- If no elements are active (e.g. at the start of the analysis) then LS-DYNA may set a very large timestep. Avoid this possibility using LCTM on *CONTROL_TIMESTEP to define a maximum timestep size for the analysis.

Running or rerunning a subset of stages

- At the end of each stage (as defined on *DEFINE_CONSTRUCTION_STAGES), LS-DYNA writes a file named (for example) *end_stage001_dynain* for the end of stage 1.
- These dynain files contain the information needed to start a new analysis from the same state: deformed node coordinates, stress and history variables for every element, etc.



Running or rerunning a subset of stages

Initial keyword file (Analysis 1):

*CONTROL_STAGED_CONSTRUCTION
0,1,3 (run from stage 1 to stage 3)
*CONTROL_...
*DATABASE_...
*MAT_...
*SECTION_...
*PART_...
*NODE
*ELEMENT_...
*DEFINE_...
*INITIAL_...
*BOUNDARY_SPC
*LOAD_...

Copy

end_stage001_dynain contains:

*BOUNDARY_SPC
*NODE
*ELEMENT_...
*INITIAL_STRESS…
*INITIAL_(other)_...

Keyword file for Analysis 2:

*CONTROL_STAGED_CONSTRUCTION
0,2,2 (run from stage 2 to stage 2)
*CONTROL_...
*DATABASE_...
*MAT_...
*SECTION_...
*PART_...
~~*NODE~~
~~*ELEMENT_...~~
*DEFINE_...
~~*INITIAL_...~~
~~*BOUNDARY_SPC~~
*LOAD_...
*INCLUDE
(path)/end_stage001_dynain

Remove keywords that are present in the dynain file and any *INITIAL cards; add *INCLUDE reference to the dynain file

Limitations

- Staged Construction capabilities are available only for certain element types and formulations.
- This information applies to versions up to and including R10.
- *ELEMENT_SOLID: ELFORM=1,2,10,15
- *ELEMENT_SHELL: ELFORM=1-11,16,17
- *ELEMENT_BEAM: ELFORM=1,2,3,6,9,11,12
- Further ELFORMs, and support for *ELEMENT_TSHELL, will be added in future LS-DYNA releases.