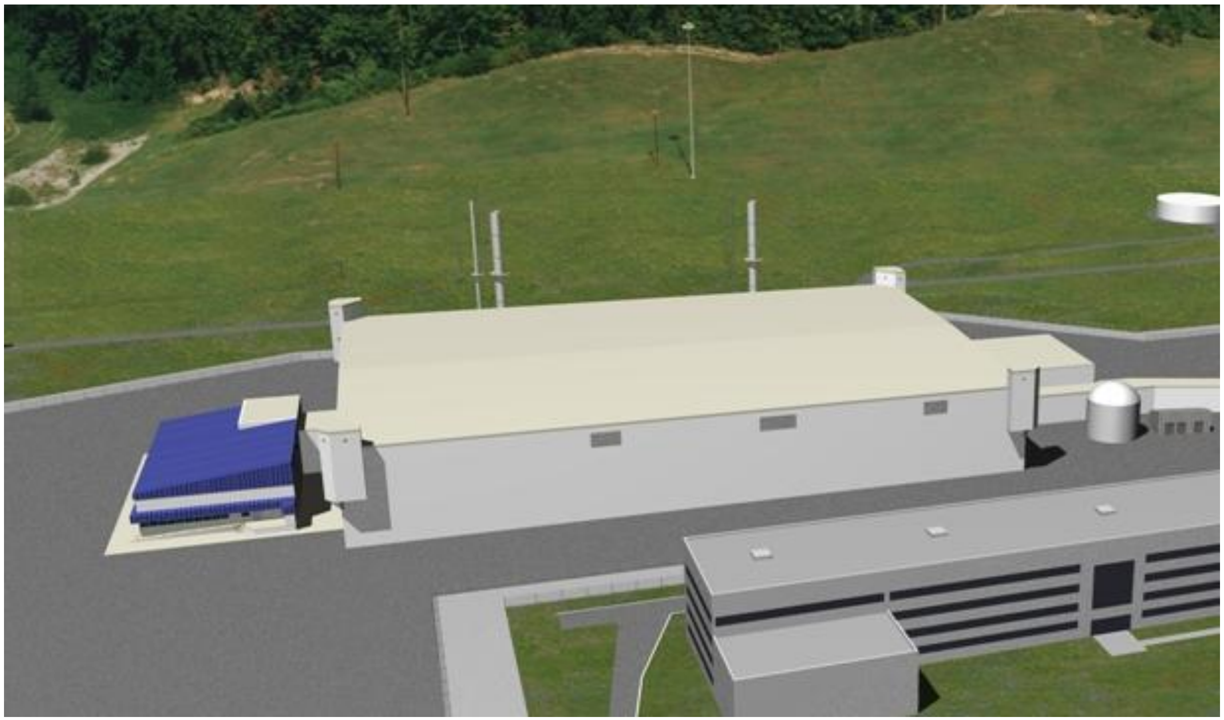
The Uranium Processing Facility (UPF) Finite Element Meshing Discussion



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Purpose of Presentation

- Design vs. Analysis
- Discuss the mesh criteria
- Discuss the evolution of the mesh of the UPF main building model
- Discuss how the mesh affects the analysis process

FEM Modeling

- GTStrudl typically used for DOE projects.
- Mesh size is important
- What is to be captured?
- How complex is the system?
- Current criteria set to capture in-plane and out-of-plane response.

ASCE 4-98 Mesh Criteria

- ASCE 4-98
  - Section 3.1.1.3.2: The finite element model shall produce responses that are not significantly affected by further refinement in the element size and shape.
  - Section C3.1.1.3.2: The selection of element sizes is essentially an exercise of engineering judgment, since the "true solution" to which the results can be compared is often not known. Even though refinement of element sizes generally increases accuracy, continued refinement is often neither necessary nor practical. In the absence of definitive guidelines, the requirement in Section 3.1.1.3.2 is considered sufficient. However, selection of mesh size and shape based on comparable past experience is also acceptable in lieu of multiple analyses using successively refined mesh.

Criteria

- ASCE 4-98
  - Section 3.1.1.1: When significant coupling exists between horizontal and vertical structural responses, one combined analytical model (a three-dimensional model) shall be used for the seismic response analysis. Otherwise, separate analytical models for horizontal and vertical excitations may be used.

  → A 3-D model is essentially required, at least initially, just to justify coupling is not “significant.” This results in a larger analysis model.

UPF Mesh Criteria

Guidance on Finite Element Size for GTSTRUDL Computer Models [Note 1]

1.	**For in-plane shear forces, piers should have at least three (3) elements vertically with an aspect ratio of between 0.5 and 2.0.**
2.	**For transverse (out-of-plane) bending of slabs, element size should be the smaller of short side/6 or long side/8.**
3.	**For transverse (out-of-plane) bending of walls, a minimum of four (4) elements across spans should be used. For walls where loading gradients are significant (e.g., exterior wall resisting soil or water pressure), use the mesh size recommended for slabs.**

UPF Analysis Procedure

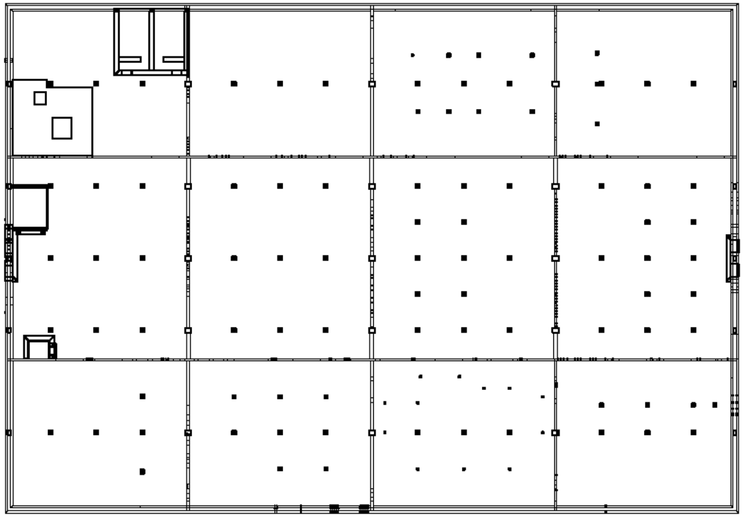
- GTStrudl Software, Version 32
- Dynamic Analysis
- 1-step solution
- Element Type
- Due to rock/concrete base, SSI results are negligible, so fixed base model intended to develop ISRS rather than a SASSI model.

Background

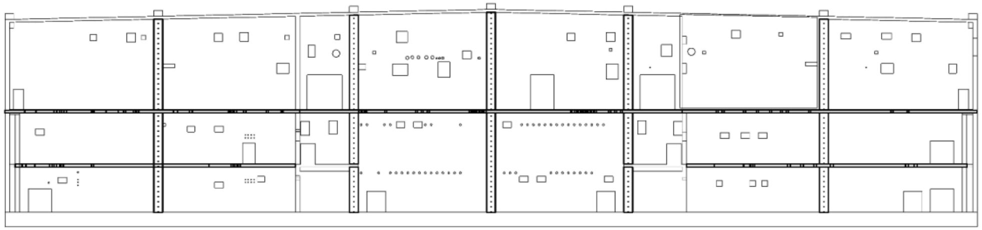
- DOE Project #1
  - 10’-15’ Element size → judged to be overly coarse for the complexity of the building
  - Final mesh added significantly more nodes and elements (1 element → 9 elements)
  - Changed from GTStrudl to SAP 2000.
  - Linear elastic computer model
- DOE Project #2
  - 15’-20’ element size deemed adequate as the building geometry was rather straightforward.
  - Linear dynamic computer model

UPF Main Building and Model Description

- UPF Main Building Footprint: 476 ft x 330 ft
- Perimeter and Interior Concrete Shear Walls
- Initially 2 floors and Steel Gravity Mezzanine
- Developed original "Coarse Model"
- Mezzanine became the "Second Floor"
- Refined mesh to 4 wall elements per story



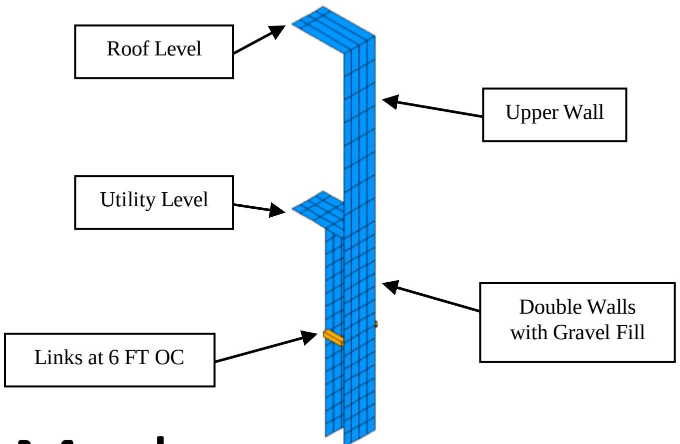
Ground Floor Plan

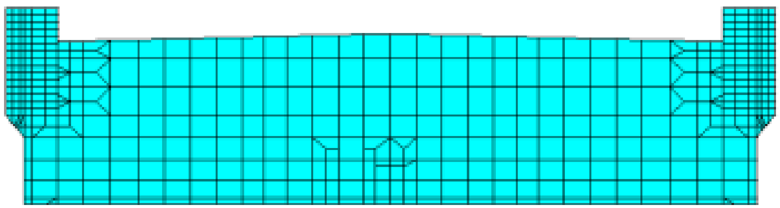


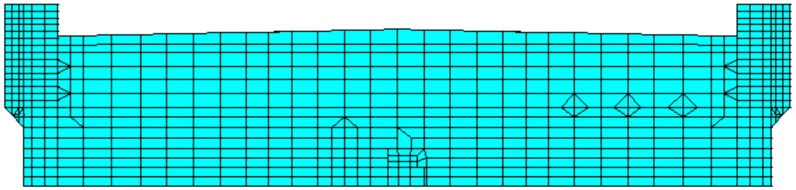
Interior Wall Elevation

UPF Finite Element Mesh

- Progression of Mesh → "Coarse Mesh" with "Tuning Fork" model

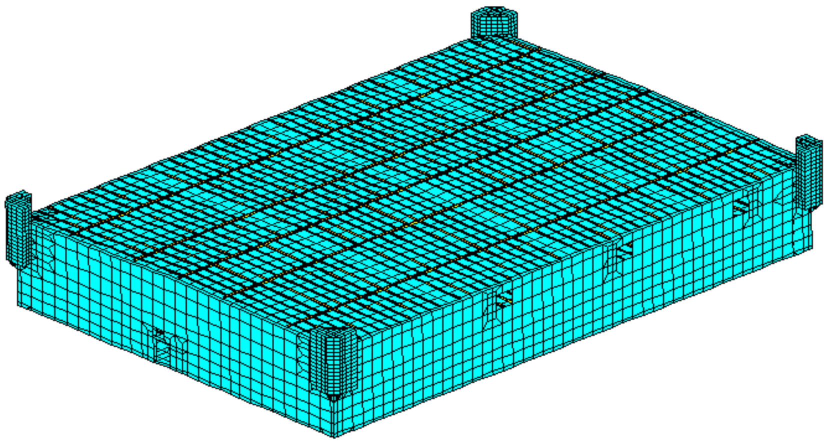




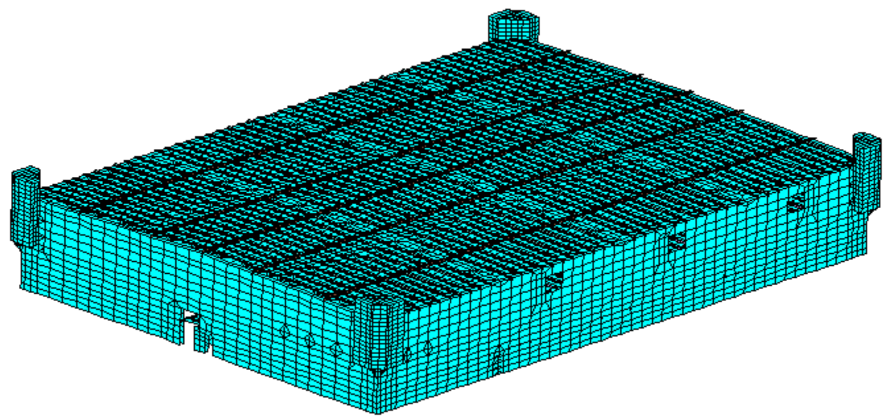


- Final Mesh
  - Mesh was originally nominally 10 ft
  - Due to inclusion of 2nd Process Floor, mesh size was changed to nominal 10 ft x 5 ft to have 4 elements between floor levels

UPF Finite Element Mesh



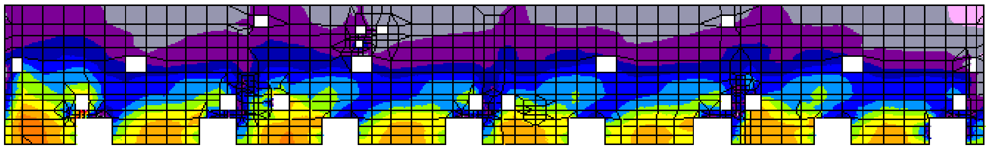
“Coarse Mesh”



“Final Mesh”

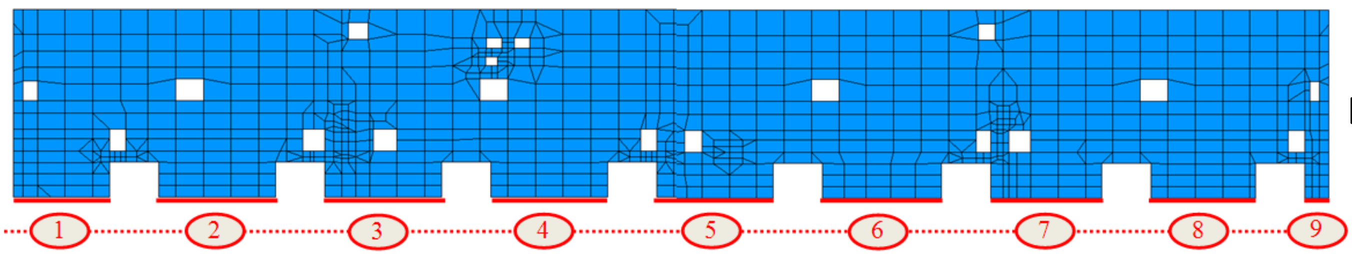
UPF Mesh Study

- Wall In-plane study

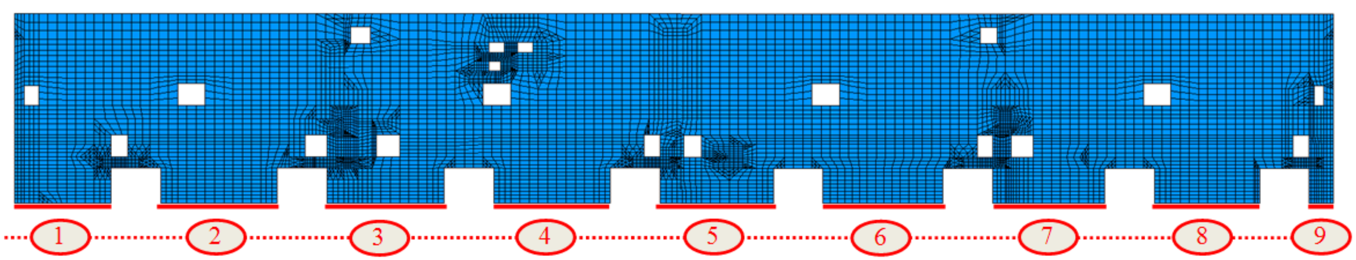


Contour Plot of the Governing In-Plane Shear Demands

Section Cut ID	In-Plane Shear		
	Design Mesh [kips]	Mesh for Study [kips]	Percent Difference
1	563	565	0.20%
2	873	880	0.77%
3	823	811	1.57%
4	894	902	0.91%
5	840	836	0.52%
6	944	948	0.45%
7	838	833	0.52%
8	814	823	0.99%
9	108	101	6.89%



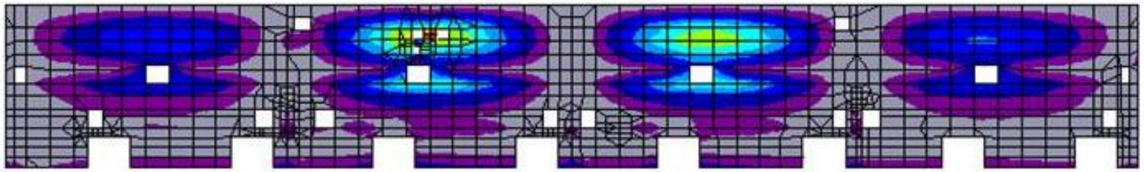
Design Mesh



Mesh used for Mesh Study

UPF Mesh Study

- Wall out-of-plane study

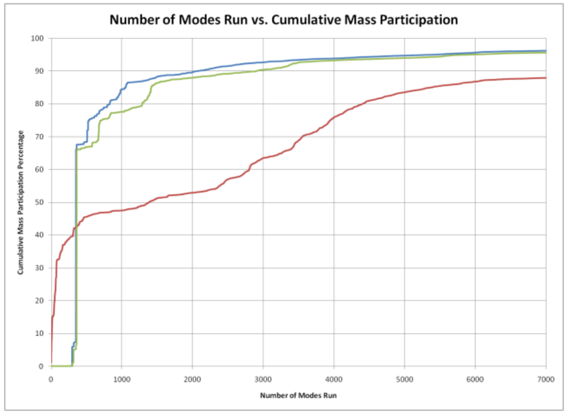


Contour Plot of the Governing Out-of-Plane Bending Demands

Out-of-Plane Moment			
Section Cut	Design Mesh [kip-ft]	Mesh for Study [kip-ft]	Percent Difference
1	120	118	1.7%
2	498	499	0.2%
3	754	750	0.5%
4	529	528	0.2%
5	681	681	0.0%
6	677	680	0.4%
7	539	529	1.9%
8	523	526	0.6%
9	463	463	0.1%
10	453	453	0.1%
11	687	686	0.2%
12	528	527	0.3%
13	529	527	0.4%
14	462	462	0.1%
15	448	450	0.5%
16	684	684	0.0%
17	529	527	0.3%
18	528	526	0.3%
19	756	755	0.2%
20	107	106	1.2%
21	381	382	0.4%
22	403	404	0.3%
23	404	408	0.8%
24	407	404	0.7%
25	405	407	0.4%
26	405	403	0.5%
27	366	363	1.0%
28	408	414	1.6%
29	285	285	0.1%
30	157	154	2.4%
31	289	289	0.0%
32	406	408	0.3%
33	404	404	0.1%
34	404	404	0.0%
35	405	406	0.3%
36	407	404	0.7%
37	404	407	0.8%
38	401	405	0.9%
39	374	371	0.6%
40	406	403	0.7%
41	405	406	0.4%
42	407	404	0.7%
43	404	407	0.8%
44	401	403	0.4%
45	383	383	0.0%

UPF Main Building Model

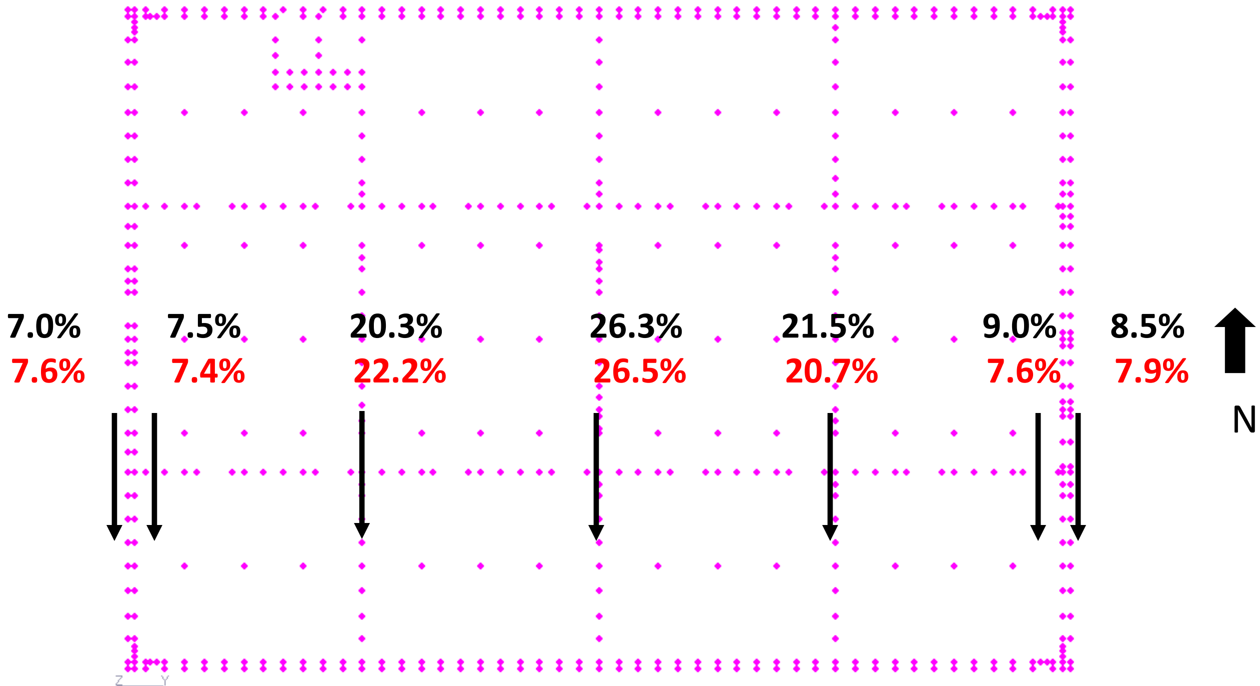
- Size of Model
  - Original Model - "Coarse Mesh" - 11040 Nodes
  - Final Model – "Final Mesh" – 28994 Nodes
- # of Modes
  - Original Model
    - 500 modes in each orthogonal direction
    - Results were combined using SRSS
  - Final Model – 7000 modes in all directions simultaneously
- Computer Requirements and Processing Time
  - Original Model – Approximately 1.5 hours for each direction (4.5 hours total) with 16 GB RAM
  - Final Model:
    - Approximately 116 hours with 48 GB RAM
    - Required GTStrudl Version 32



Focus on the Process

- Know the building's geometry
- Know the material properties of members
- Given seismic input spectra → many unknowns, considerable judgment, much uncertainty, undoubtedly conservative
- SSI analysis – shale/concrete base
- Elastic analysis and design – considerable elastic margin and inelastic response capability
- Primary response vs. secondary response

Design vs. Analysis



North-South Running Walls – Base Shear Distribution

- Black % - Original "Coarse" Mesh (~10' x 10' Mesh)
- Red % - Final Accepted Mesh

- Note that the changes are principally due to changes in the building configuration between the earlier design and the final design, and not because of mesh changes.

Conclusions

- A Universal Mesh Criteria should not be required
  - Initial Mesh was adequate for Design.
  - Final mesh and associated studies were required for the Analysis to justify the Design, Peer Review, etc.
- Static Analysis vs. Dynamic Analysis
  - Dynamic Analysis more accurate but more computationally complex
  - Static Analysis is simpler but perhaps too conservative
- The advantage of the large 3-D Model is that ISRS can be developed.
  - SASSI model for ISRS is usually much coarser