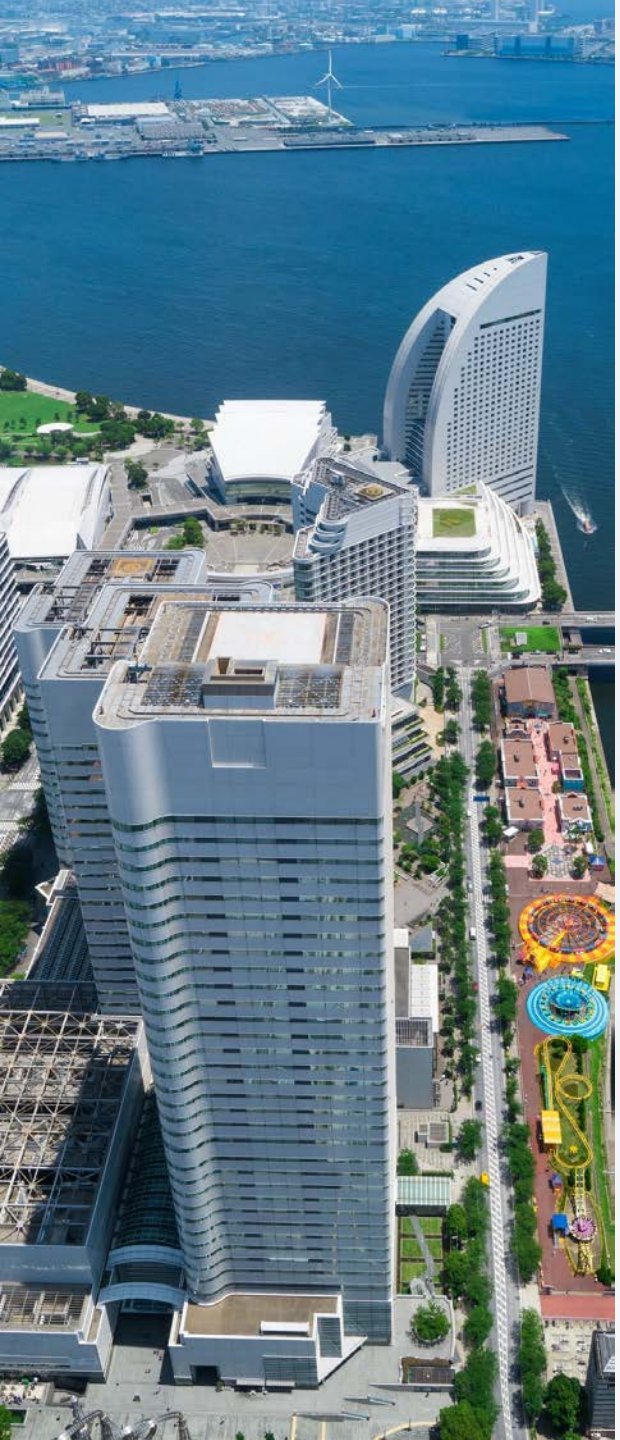


Advanced Methodology of Structural Redundancy Analysis for Optimizing Passive Fire / Cryogenic Spill Protection

Enhancing **planetary health**

16th Nov. 2021

JGC Corporation

Technical HSE Department

Hiroki Takahashi

CONTENTS

1. Introduction of Redundancy Analysis

Enhancing **planetary health**

1. Introduction of Redundancy Analysis

Passive Fire Protection (PFP) & Cryogenic Spill Protection (CSP)

Material on structural steels to reduce the risk of escalation from fire or cryogenic spill exposure.

Concerns

- Material and Installation Cost
- Corrosion under Insulation (CUI)

➡ Optimization of PFP/CSP application is beneficial

Dense Concrete

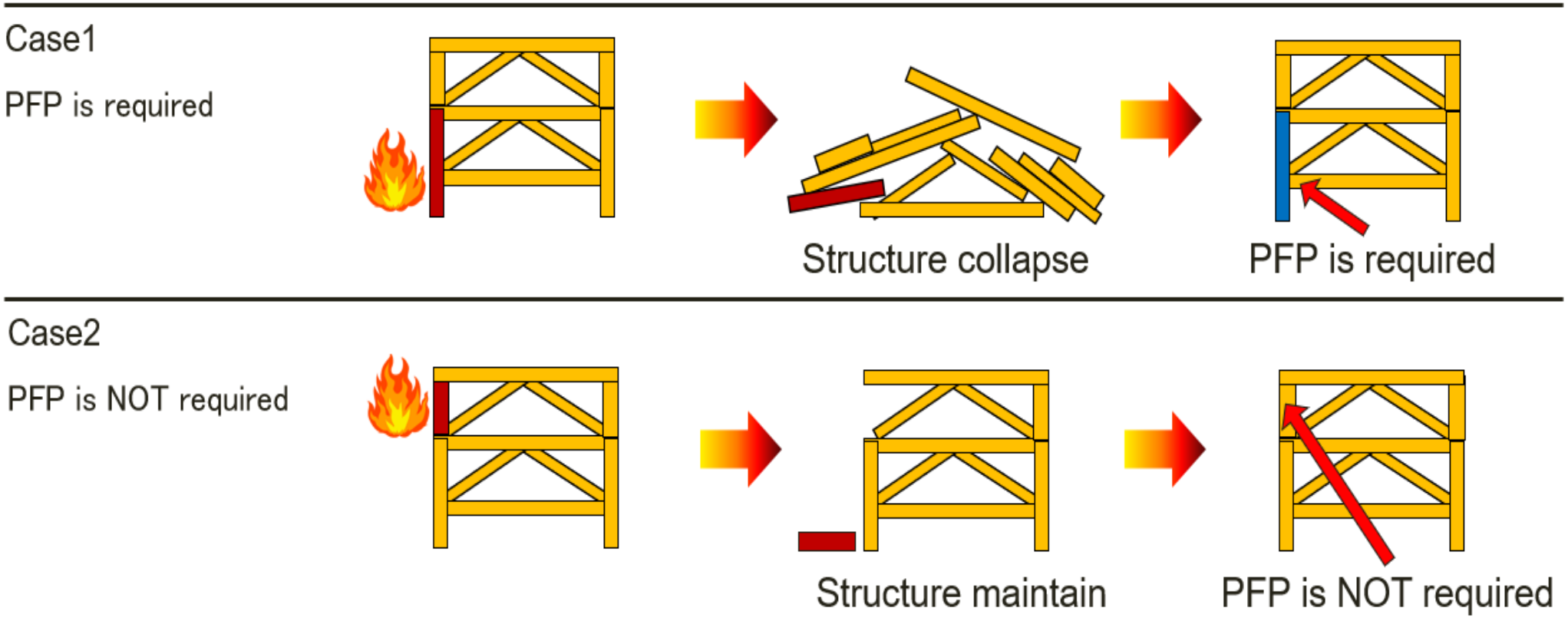
Lightweight Cementitious

Intumescent

1. Introduction of Redundancy Analysis

Redundancy Analysis

Analysis to optimize PFP application by identifying the critical members for the structure's integrity.



Concept of Redundancy Analysis

1. Introduction of Redundancy Analysis

For offshore installations, the analysis is available considering jet fire hazards.

➡ It has not been widely adopted for pool fire or cryogenic spill hazards in onshore projects.

Challenges for Conducting the Analysis

- Consuming a significant amount of computing time due to simulations by CFD, heat transfer analysis and structure analysis by FEM
- Engineering schedule is tight

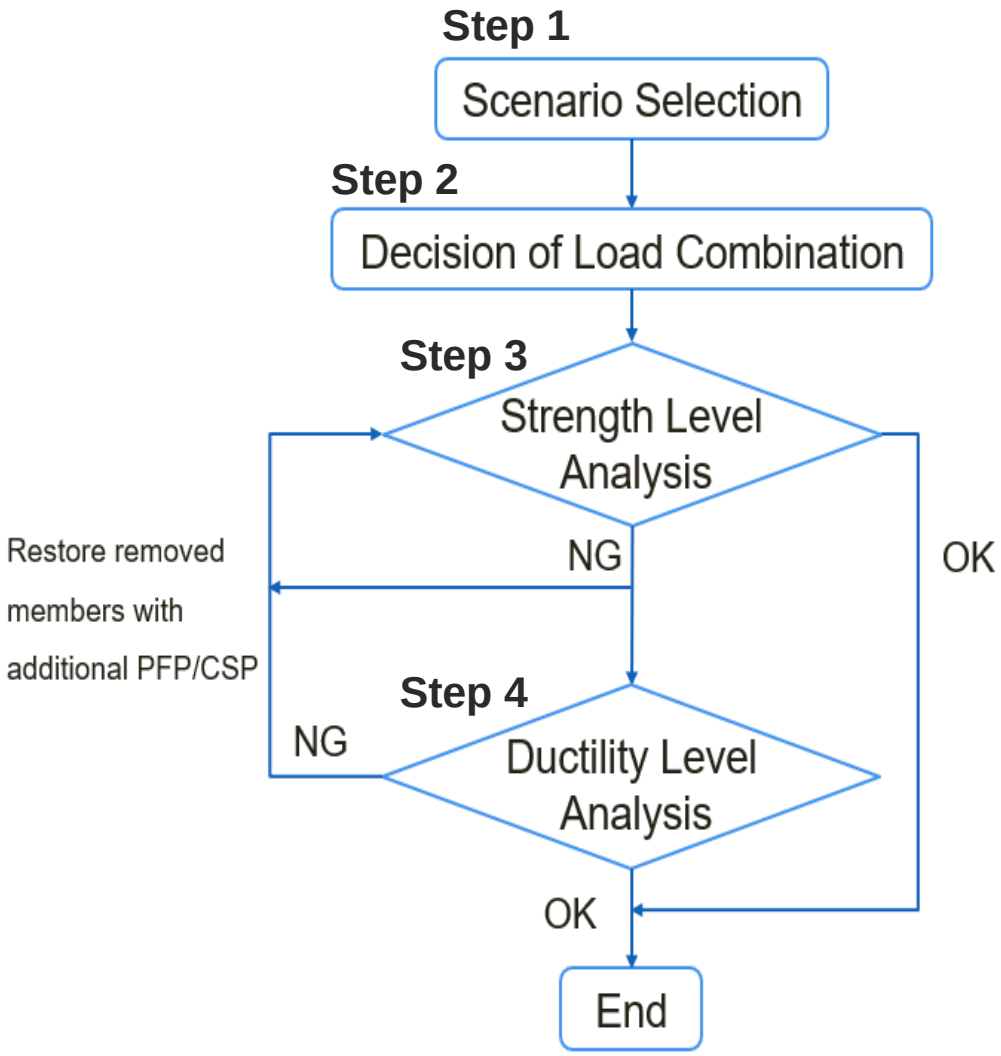
➡ Only a limited number of scenarios can be evaluated by present methodology

To apply the analysis to large onshore projects, the methodology needs to be advanced.

2. Outline of Advanced Methodology

Enhancing **planetary health**

2. Outline of Advanced Methodology



Step 1: Scenario Selection

- Select the pool fire / cryogenic spill scenario
- Identify the structural members affected by the scenario

Step 2: Decision of Load Combination

- Decide the load combination

Step 3: Strength Level Analysis

- Linear elastic analysis
- Remove the members affected by the scenario from the structural analysis model
- Calculate the utilization ratio and compare with criterion

Step 4: Ductility Level Analysis

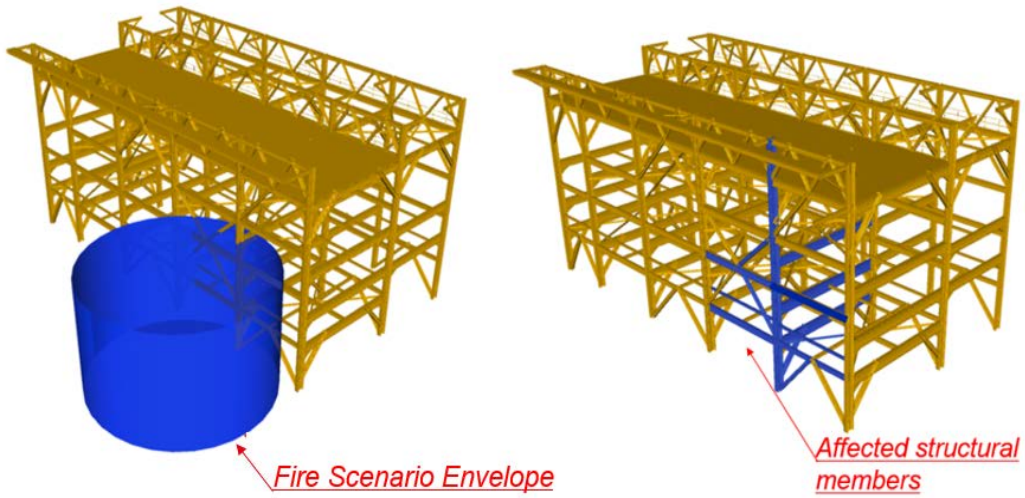
- Nonlinear elastic-plastic analysis
- Confirm if the residual deformation is acceptable
  (There is no progressive deformation)

2. Outline of Advanced Methodology

Step 1: Scenario Selection

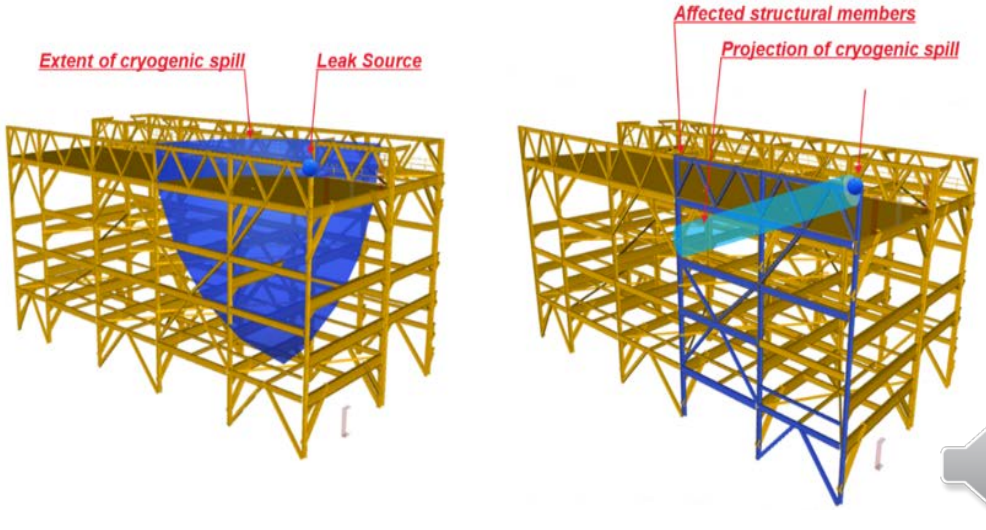
Pool Fire Scenario

1. Identify the fire potential equipment based on API 2218
2. Represent the fire scenario envelope in 3D model
3. Identify the structural members affected by pool fire scenario



Cryogenic Spill Scenario

1. Assume the release hole size
2. Calculate the extent of cryogenic spill
3. Identify the structural members affected by cryogenic spill considering several discharge direction and dripping down



2. Outline of Advanced Methodology

Step 2: Decision of Load Combination

The load combination is an important setting in the structural model.

Example 1 (FABIG Technical Note 13)

- Only gravity load is considered
- Low-frequency load (e.g. wave or wind loads) is not considered

Example 2 (ASCE 7-10)

- Gravity load
- Snow load
- Rain load

Load combination must be carefully decided since it affects the result of analysis

2. Outline of Advanced Methodology

Step 3: Strength Level Analysis

Conventional Linear Elastic Analysis

Software: STAAD.Pro (Bentley)

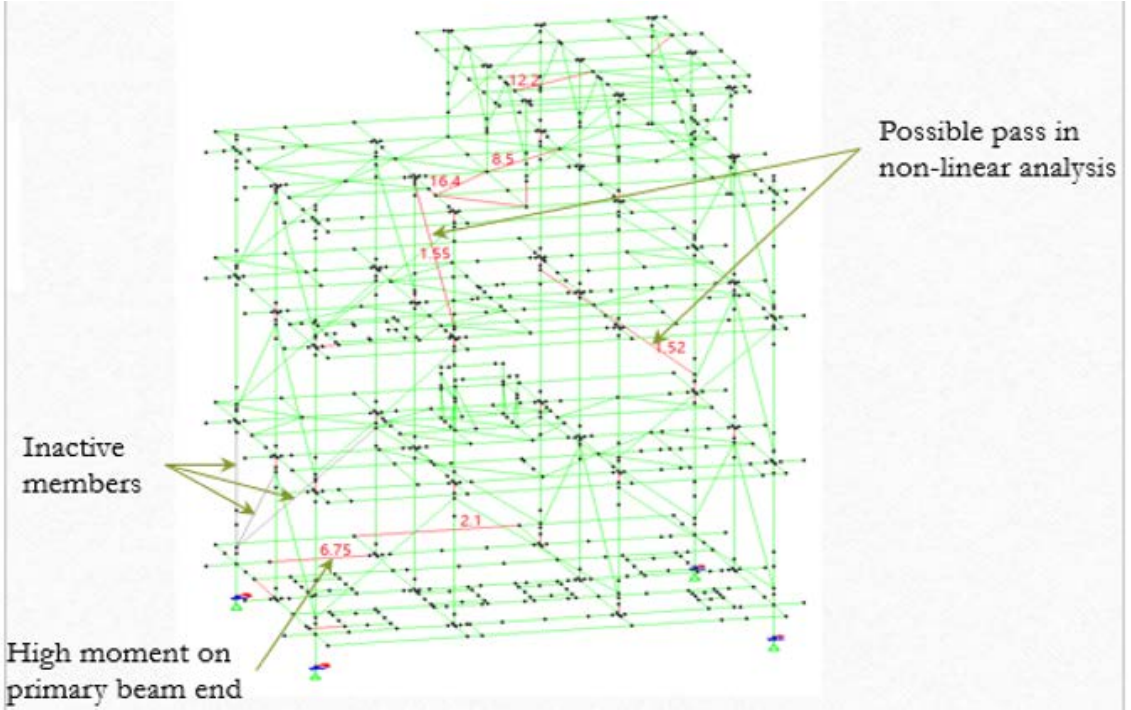
Criterion: The utilization ratio (μ_0) of 1.5 (API RP 2FB)

$$\mu_0 = \frac{\text{Actual Stress}}{\text{Allowable Stress}}$$

1. Remove the structural members from the model
2. Calculate the utilization ratio (μ_0)
3. If $\mu_0 < 1.5$, the analysis is completed and no PFP/CSP is required
4. If $\mu_0 > 1.5$, there are two options.

- Restore some of the removed members with PFP/CSP
- Proceed with Ductility Level Analysis

5. When some members are restored with PFP/CSP, the Strength Level Analysis is conducted again.



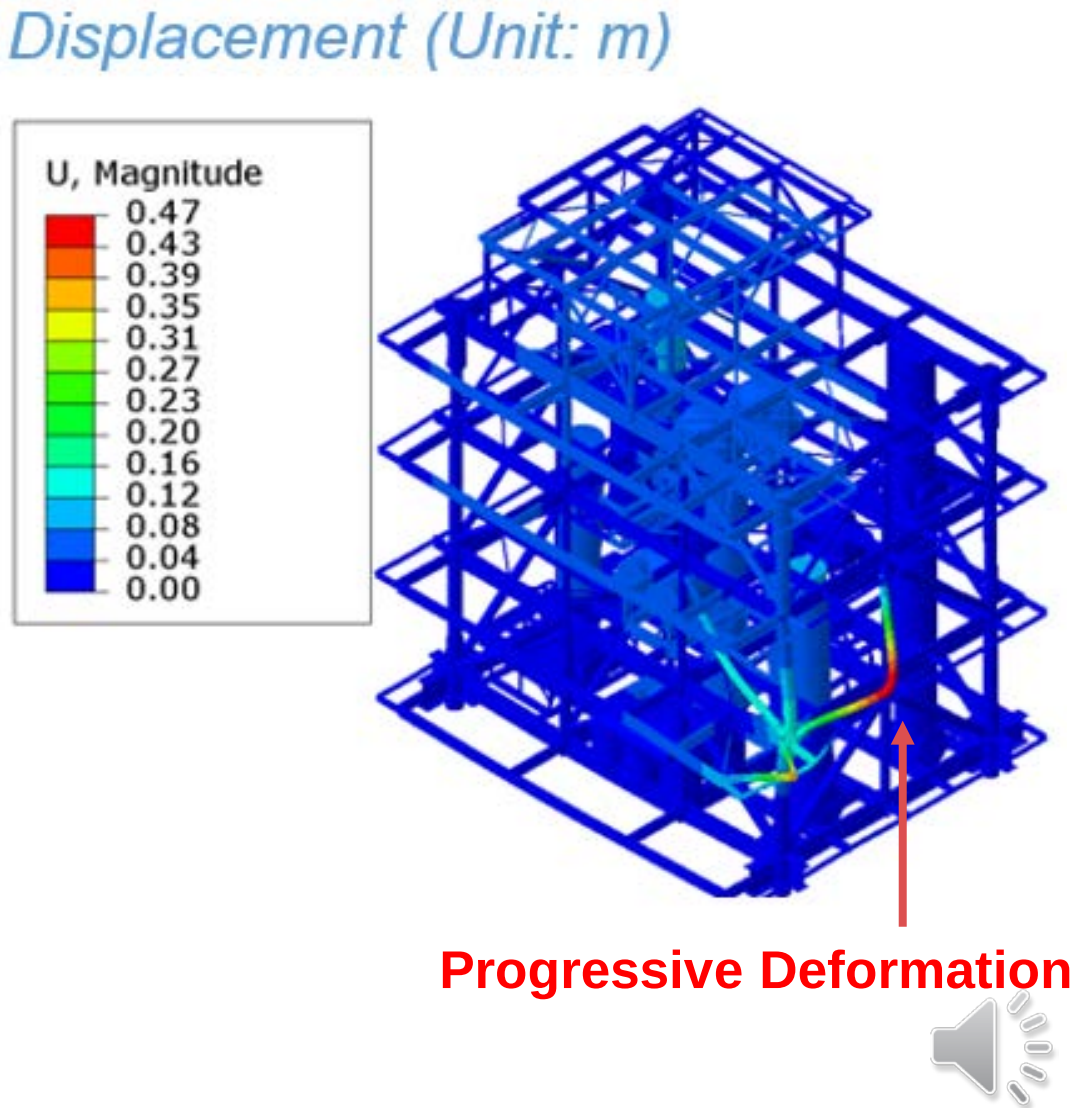
2. Outline of Advanced Methodology

Step 4: Ductility Level Analysis

Nonlinear Elastic-Plastic Analysis

Software: Abaqus (Dassault)

1. Import the structural model used in strength level analysis
2. Confirm if the residual deformation is acceptable, for example, there is no progressive deformation
3. If the result exceeds the tolerance, additional PFP/CSP is applied and re-run the analysis until the result is acceptable.



3. Case Study _ Pool Fire Scenario

Enhancing **planetary health**

3. Case Study _ Pool Fire Scenario

Step 1: Scenario Selection

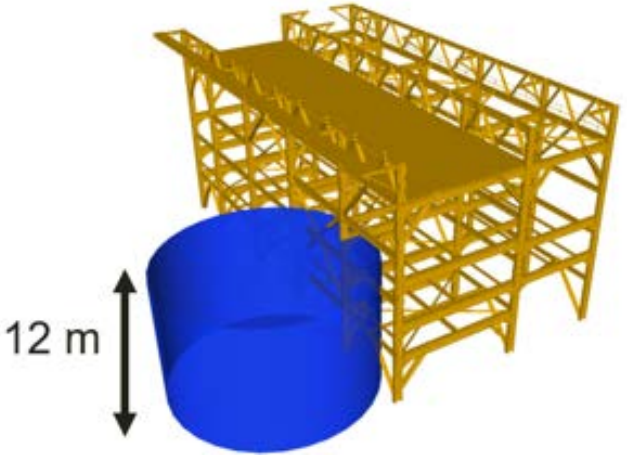
- The following two pool fire scenarios are studied.

	Pool Fire Conditions			Structure
	Source	Radius	Height	
Scenario 1	Pump	9 m	12 m	Piperack
Scenario 2	ACHE	9 m	Up to highest member	Piperack with ACHE

- For Scenario 1, a pool fire originates from a pump near the structure.
  Only a part of structure is within the fire scenario envelope.

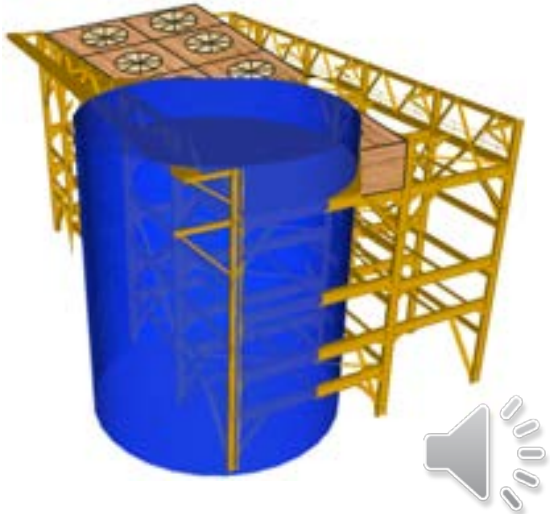
- For Scenario 2, a pool fire occurs under an air cooled heat exchanger.
  Pool fire escalates vertically due to an upward air current.
  Many structural members are within the fire scenario envelope.

Scenario 1



ACHE

Scenario 2



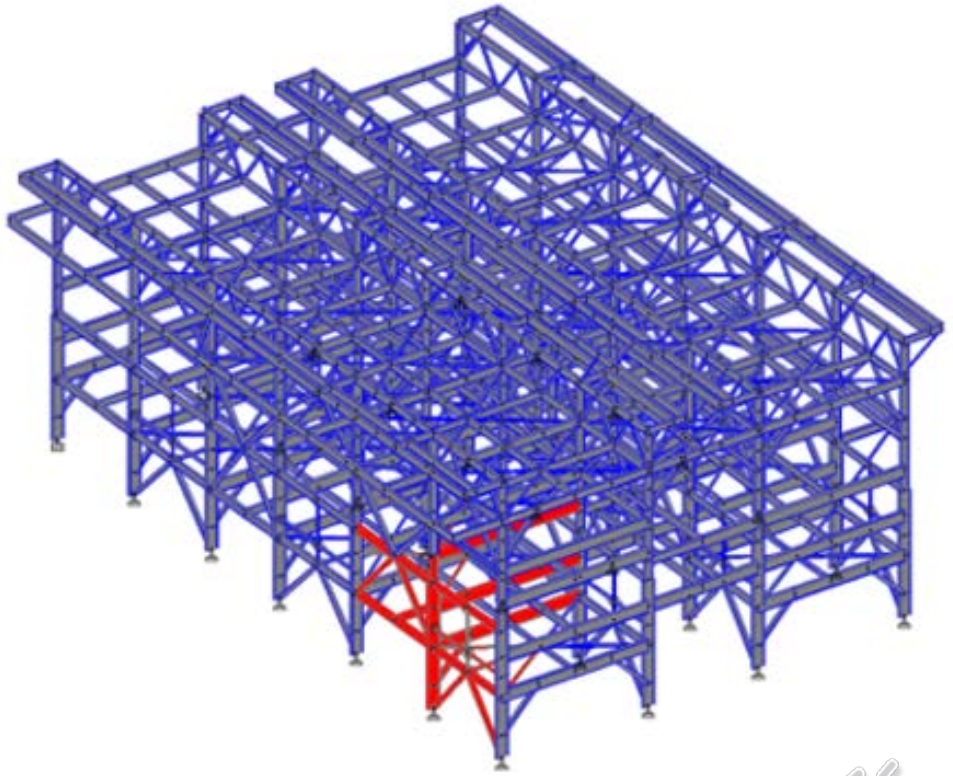
3. Case Study _ Pool Fire Scenario

Step 2: Decision of Load Combination

- Gravity load with notional load is considered based on ASCE 7-10 for both scenarios

Step 3: Strength Level Analysis for Scenario 1

Red highlighted members are removed from structural model.



Result

No member is failed.

(Maximum utilization ratio: 0.99)

→ Structure's integrity can be maintained without PFP.

→ No further assessment is required.

3. Case Study _ Pool Fire Scenario

Step 3: Strength Level Analysis for Scenario 2

Red highlighted members in Figure 1 are removed from structural model.

(The members dedicated to support ACHE are not removed)

Result

Red highlighted members in Figure 2 are failed.

(Maximum utilization ratio: 3.64)

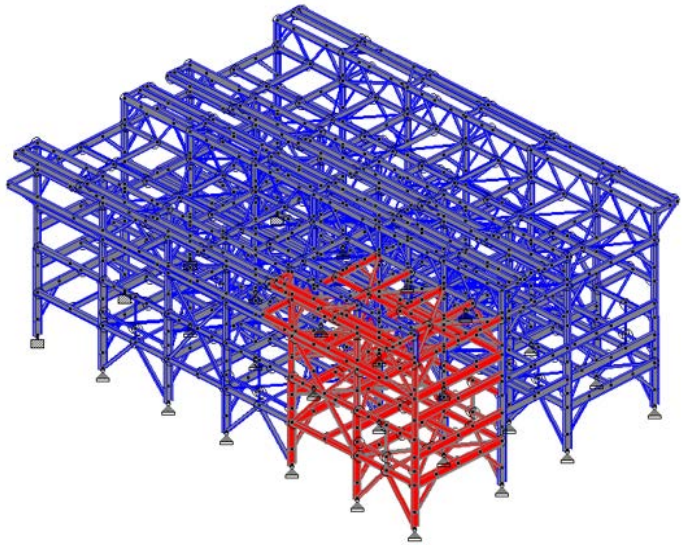


Figure 1 Removed Members

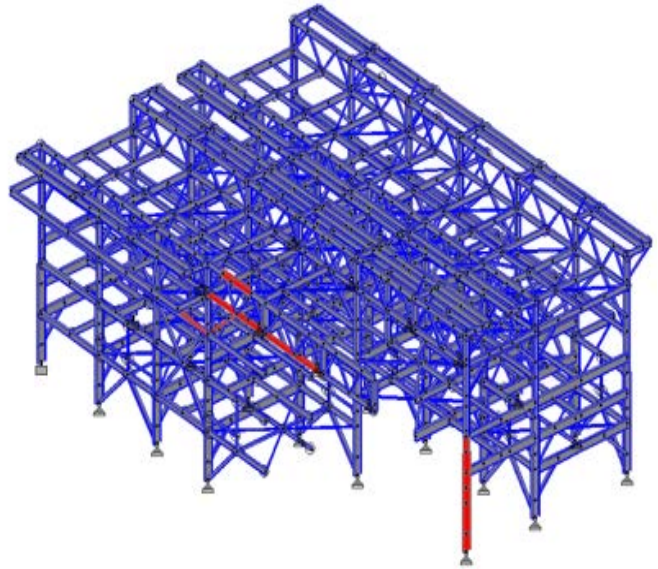


Figure 2 Failed Members

3. Case Study _ Pool Fire Scenario

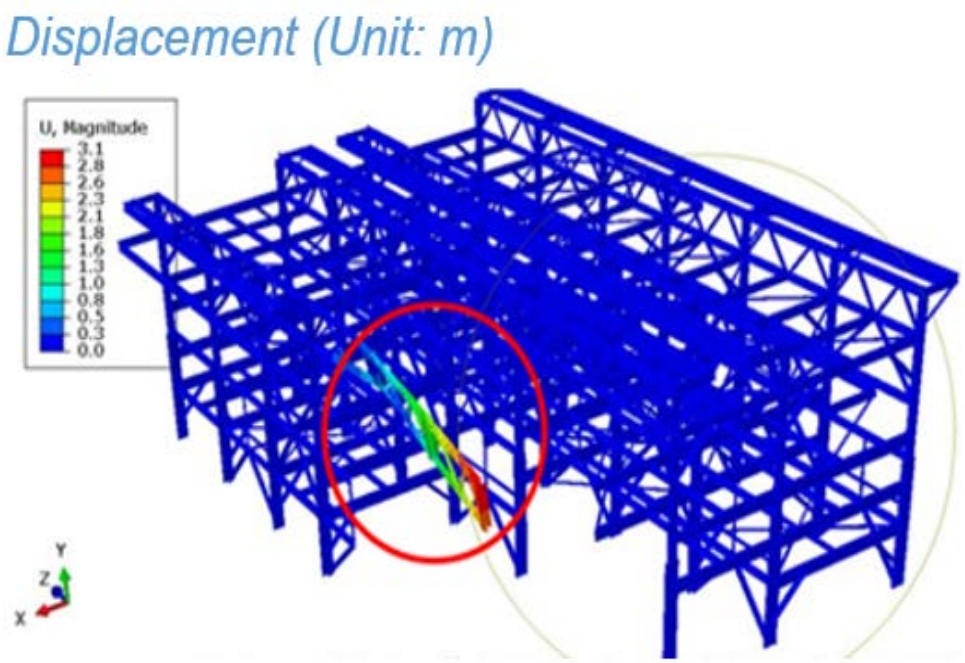
Step 4: Ductility Level Analysis for Scenario 2

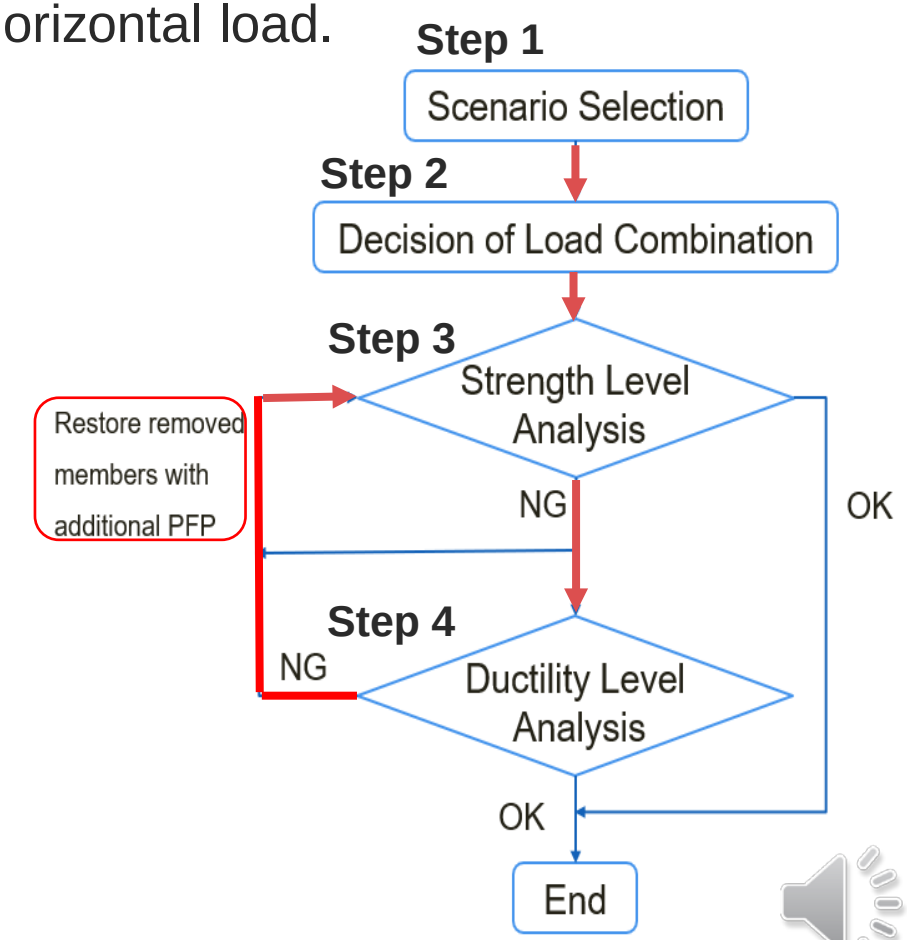
Result

ACHE cantilever members are failed due to displacement from horizontal load.

→ Some removed members need to be restored with PFP

→ Conduct Step 3: Strength Level Analysis again





3. Case Study _ Pool Fire Scenario

Re-Step 3: Strength Level Analysis for Scenario 2 (with PFP)

Red highlighted members in Figure 3 are restored with PFP and strength level analysis is conducted again.

Result

Red highlighted members in Figure 4 are failed.

(Maximum utilization ratio: 2.1)

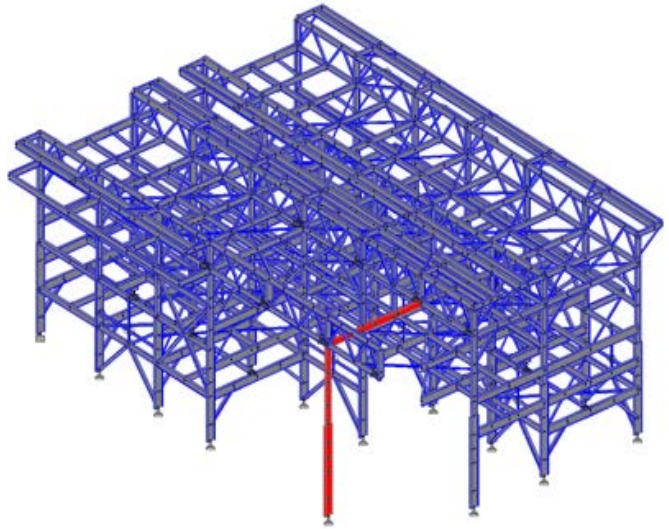


Figure 3 Restored Members

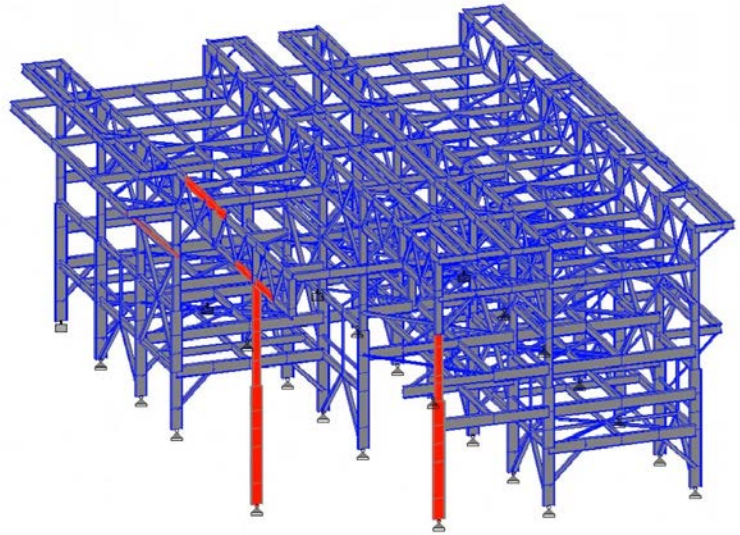


Figure 4 Failed Members

3. Case Study _ Pool Fire Scenario

Re-Step 4: Ductility Level Analysis for Scenario 2 (with PFP)

Result

The displacement of members is not significant (Maximum 0.04 m)

→ No further PFP is required.

Figure 6 shows the final result of the PFP applied members

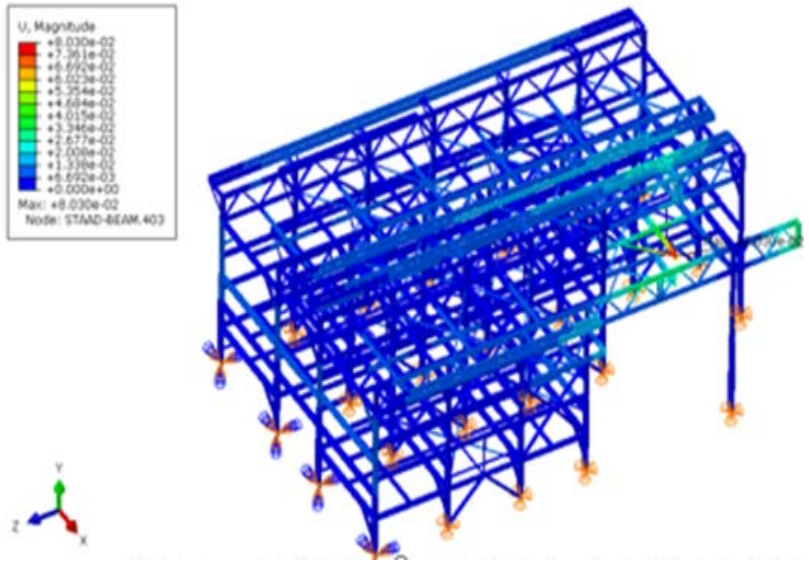


Figure 5 Result of Ductility Level Analysis

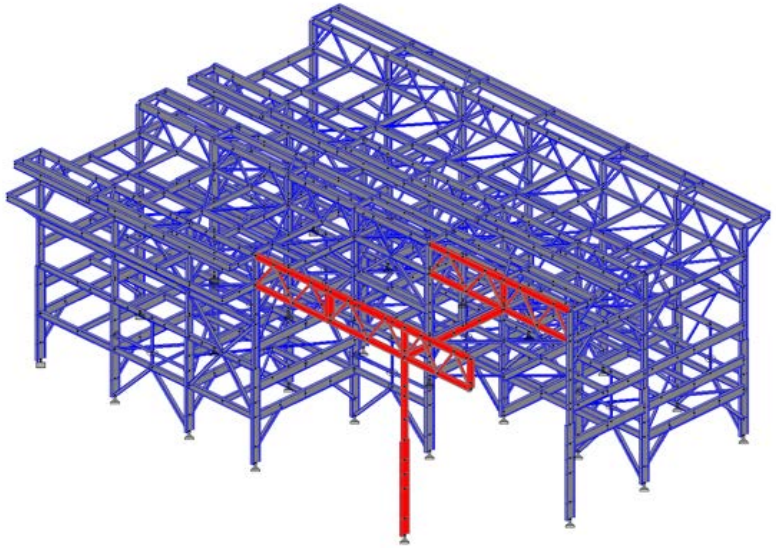


Figure 6 Final Result of PFP application

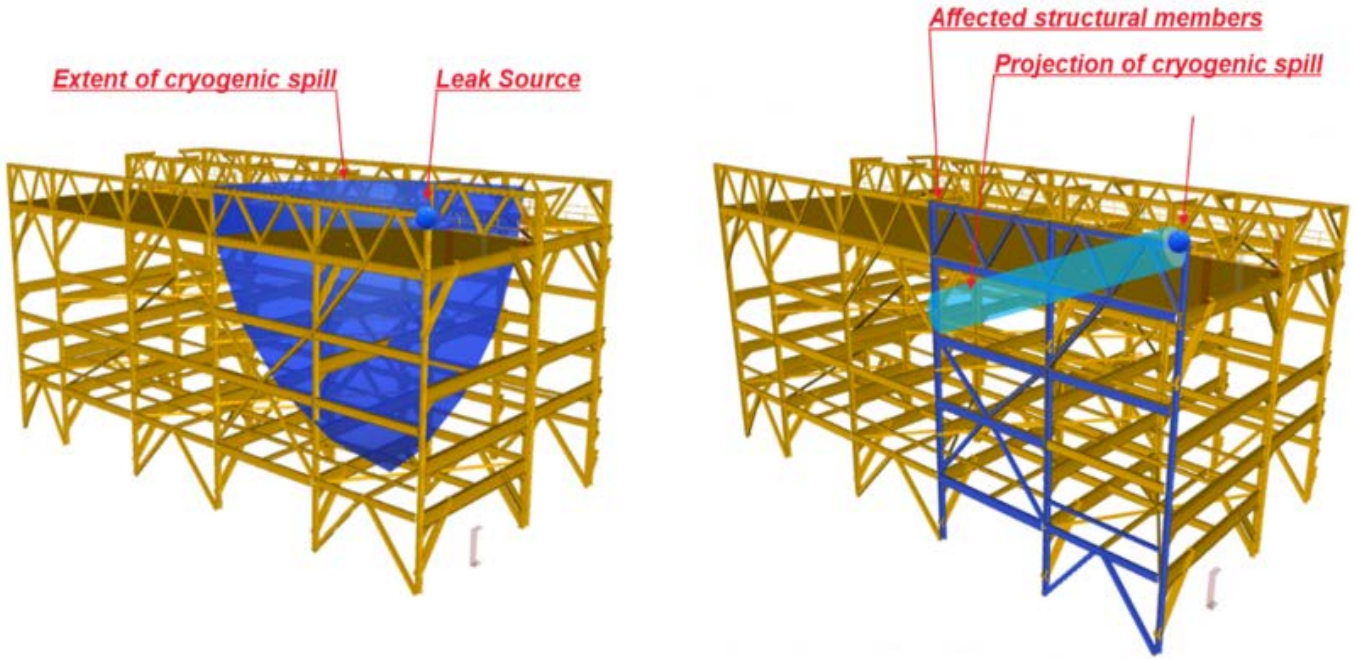
4. Case Study_Cryogenic Spill Scenario

Enhancing **planetary health**

4. Case Study _ Cryogenic Spill Scenario

Step 1: Scenario Selection

- Cryogenic spill release originated from ACHE is considered
- The extent is calculated by consequence software (PHAST)
- The release is treated as a cylinder shape
  - Extent: 18.0 m, Base diameter: 1.0 m
- Severest direction is selected considering the type and number of affected structural members.
- The cryogenic dripping down along the impinged structure is also considered



4. Case Study _ Cryogenic Spill Scenario

Step 2: Decision of Load Combination

- Gravity load with notional load is considered based on ASCE 7-10

Step 3: Strength Level Analysis

Red highlighted members in Figure 7 are removed from structural model

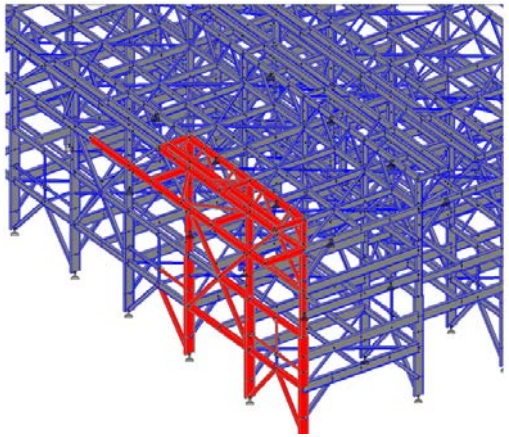


Figure 7 Removed Members

Result

One vertical brace in Figure 8 is failed

(Maximum utilization ratio: 1.66)

➡ Although this utilization ratio is not high, ductility level analysis is conducted to confirm whether CSP is required or not

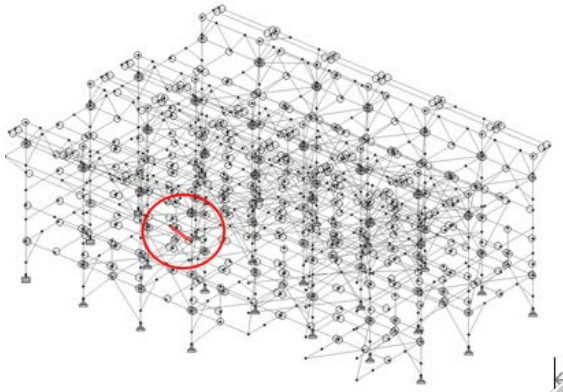


Figure 8 Failed Members

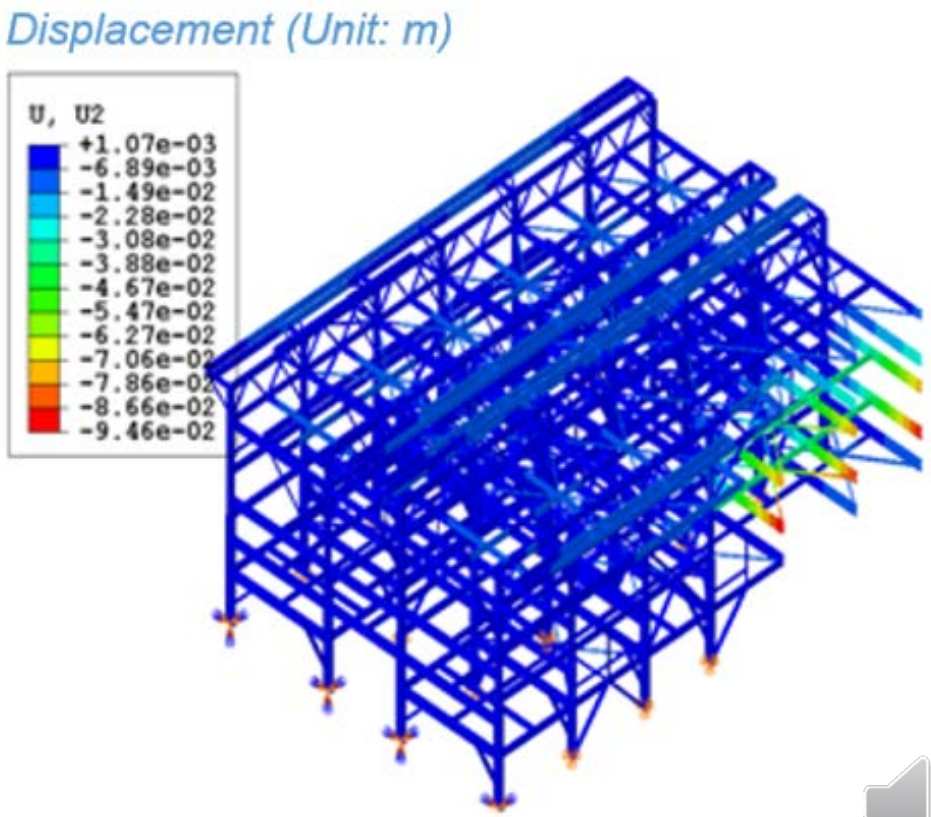
4. Case Study _ Cryogenic Spill Scenario

Step 4: Ductility level Analysis

Result

The displacement of members is not significant (Maximum 0.095 m)

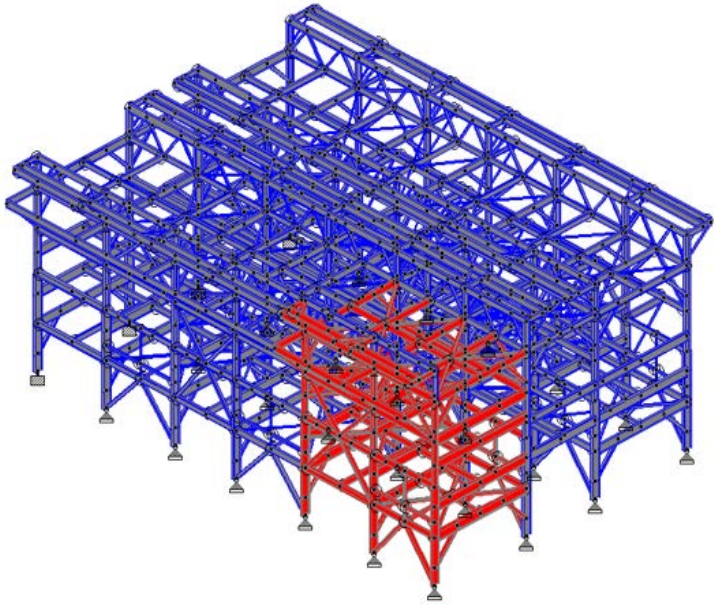
- No CSP is required
- No further assessment is required.



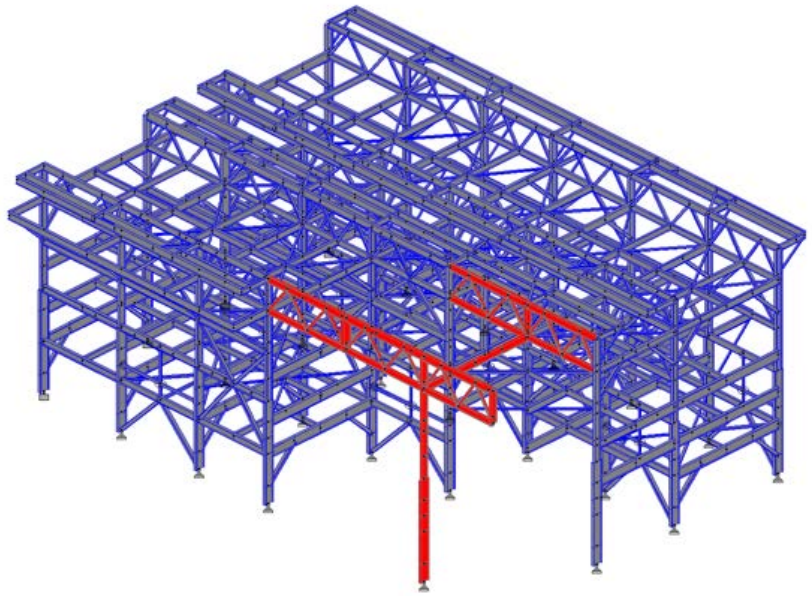
5. Conclusion

5. Conclusion

- An advanced methodology for structural redundancy analysis has been established for pool fire and cryogenic spill hazards at onshore facilities.
- The established methodology has been demonstrated.
- PFP and CSP applied area can be optimized.
- The advanced methodology can save time since simulations are not required and a number of FEM analysis is reduced.



Traditional Methodology



Advanced Methodology

Contact Information

If any question, please contact with the following persons by e-mail or phone call.

● Hiroki Takahashi

Engineer, Technical HSE Department, JGC Corporation Energy Solutions Center

MAIL: takahashi.hir@jgc.com

TEL: +81-45-682-8506

● Yoshinori Hiroya

Principal Engineer, Technical HSE Department, JGC Corporation Energy Solutions Center

MAIL: yoshinori.hiroya@jgc.com

TEL: +81-45-682-8505

● Ken Kobayashi

Senior Principal Engineer, Technical HSE Department, JGC Corporation Energy Solutions Center

MAIL: kobayashi.k@jgc.com

TEL: +81-45-682-8505